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SYSTEM AND COST EFFECTIVENESS MANUAL FOR SYSTEM DEVELOPERS

Lockheed Missiles & Space Company

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

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SYSTEM AND COST EFFECTIVENESS MANUAL FOR SYSTEM DEVELOPERS

Allen Chop

Lockheed Missiles & Space Company

FOREWORD

This document is the Final Report submitted by Lockheed Missiles & Space Company, Sunnyvale, California, under Contract F30602-68-C-0209, Project 5519, Task 551907, with Rome Air Development Center, Griffiss Air Force Base, New York. Lockheed's report number is DO 52535. Jerome Klion, EMNRS-2, was the RADC Project Engineer.

This manual provides procedural and technical guidelines for the implementation of system and cost effectiveness analysis for different classes of Air Force systems throughout any life cycle phase during which design and technical program tasks are being defined, evaluated, or changed. As such, the procedures and techniques contained herein can be used to implement the general and specific requirements of MIL-STD-499, Military Standard, System Engineering Management. Additionally, the manual is responsive to the primary objective, policy, and criteria of Air Force Regulation 375-7, Performance Measurement (PM) for Selected Acquisitions and the information requirements of Air Force Authorized Data Item, S-145, System/Cost Effectiveness Program Plan of AFSCM/AFLCM 310-1, Management of Contractor Data and Reports.

Distribution of the report is restricted under the provisions of the U.S. Mutual Security Acts of 1949.

This Technical Report has been reviewed and is approved.

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ABSTRACT

The manual defines and describes the system and cost effectiveness management implementation process which will provide both Air Force and contractor management with the necessary mission responsive criteria, authoritative perspective, and visibility for critical system development decisions. Technical activities, procedures, guidelines, and objectives for the efficient and meaningful formulation of effectiveness criteria, and for the evaluation and assurance of effectiveness, are detailed on a step-by-step and time-phased, action basis for each of the systems management phases of Concept Formulation, Contract Definition, and Acquisition. Further, the integration of the effectiveness implementation procedures with the system program management procedures (AFSCM 375-4) and systems engineering management procedures (AFSCM 375-5) is outlined for each major effectiveness activity and polarized with information flow networks. Also provided in the manual are guidelines for the necessary Air Force and contractor management actions to implement the effectiveness process and to insure attainment of its objectives. Finally, specific application guidelines are detailed for each of six major classes of Air Force systems to provide intelligence on the needed technical translation of the general effectiveness procedures for specific applications.

EVALUATION

This program had as its objective the development of a manual for use during the various phases of system development. It was the intent of the effort to provide needed guidelines for both government and industry pertinent to formulation and implementation of called-for system effectiveness evaluations. The guidelines in question were to be particular to such activities as (1) determination of appropriate system effectiveness figures of merit, (2) specification of appropriate supporting data needs, (3) specification of necessary particular technical analyses, and (4) definition of practical implementation procedures.

All objectives of the program were realized. This final report contains the aforementioned details broken down for six particular classes of Air Force systems and subsystems (Command and Control, Warning and Detection, Aircraft, Ballistic Missile, Booster, and Satellite). Specific guidelines relative to analysis, scope and makeup, data availability and sources, and ancillary evaluation activities are spelled out for each of the three phases of system development (Conceptual, Definition, and Acquisition). Necessary follow through and coordinating actions between phases are also included.

In addition to the above, in order to integrate system effectiveness activities with the other tasks normally called for in system development, the system effectiveness analysis efforts called for are coordinated with pertinent AFSCM 375 and AFSCM 310 tasks and follow the framework of each such task. The procedures and techniques spelled out in the final report are also structured to implement the general and specific system effectiveness activities called for in MIL-STD-499 (System Engineering Management).

One of the pitfalls in the path of successful application of system effectiveness is a general lack of knowledge (or, on the other hand, existence of erroneous impressions) pertinent to how system effectiveness analysis should be applied to the system development process. The only way to combat this situation is by providing documents such as this manual which provide the necessary knowledge and guidance. This document is a major step to this end. It will be of aid to both industry and government. Steps are under way to combine this manual and the completed RADC System/Cost Effectiveness Notebook into an official Air Force document. (It is also possible that the manual alone will be, in the interim, called out as an exhibit on all future AFSC systems.) In addition to this, the usual DDC distribution will be provided this report such that it reaches general industry in as short a time period as possible.

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INTRODUCTION

Summary

The system and cost effectiveness technology embodies scientific and engineering concepts and techniques which can be used to facilitate the creation and selection of the system design with the best balance of technical performance, schedule, and total cost to meet mission and operational requirements. A management implementation process is identifiable and can be established, with distinct technical elements and practical procedures, for the formulation of effectiveness criteria, and for the evaluation and assurance of system and cost effectiveness in Air Force systems. System and cost effectiveness has a dual technical meaning. It denotes a management science. It also denotes measurable system parameters of the overall technical performance and the cost value or merit of a system. The manual addresses both of these aspects of effectiveness, and is designed to provide Air Force and contractor management personnel with the necessary authoritative perspective and the consistent but unrestrictive guidelines for the implementation of the system and cost effectiveness process. An emphasis is placed on technical elements and procedures that will accommodate the normal development, procurement, and specification practices of current system developers. Further, to facilitate use of the manual, implementation and formating features have been incorporated. These include (1) chapter summaries, (2) military management phase orientation, (3) technical management guidelines, (4) specialized application guidelines for specific classes of Air Force systems, and (5) an example illustrating the implementation procedures.

1-1 GENERAL

The system and cost effectiveness technology is a management science for top-level decision-making. It encompasses scientific and engineering concepts and techniques. When formally applied early and periodically throughout a system's design life, the technology can provide continuous visibility into the coherency and proper balance of a total system design. System and cost effectiveness procedures and technical elements permit a multiplicity of system design and use criteria, such as mission requirements, technical performance parameters, design factors, and resource allocations to be integrated and evaluated within a common framework. The expedient and efficient implementation of the technology provides a logical evaluation of how successfully mission requirements and operational needs are translated into appropriate systems and system descriptions representing the best combination of technical performance, schedule, and total cost.

The scientific and engineering foundation of the system and cost effectiveness technology is based on sound engineering and management principles, physical laws, probability concepts, and empirical relationships. The technology draws and builds upon existing concepts and techniques employed by the highly complementary and creative systems engineering disciplines that it integrates. A management process can be defined and established for the practical implementation of the system and cost effectiveness technology during the conceptual, definition, development, and operational evolutionary phases of Air Force military systems. Identifiable with this management implementation process is a distinct series of activities. These activities consist of technical elements and procedures for the formulation of criteria, and for the evaluation and assurance of system and cost effectiveness.

In addition to its role as a management science, system and cost effectiveness denotes measurable system parameters representing the conglomerate, interactive influences of the diverse technical, schedule, and cost parameters of a system.

In this context, system effectiveness refers to a quantitative measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a measure of the technical performance value(s) or merit(s) of the system to achieve specific mission and operational requirements. A cost effectiveness measure relates the system effectiveness measure (value received) to the resource cost.

1-2 PURPOSE OF MANUAL

This Air Force manual serves multi-purposes. However, the primary intent is to meet the technical need for a general management manual which will provide consistent, but unrestrictive, guidelines and procedural guidance for accomplishing the necessary actions in implementing a system and cost effectiveness process by both Air Force technical and procuring activities and industrial contractors. Consistent with this purpose, the manual describes specific technical elements with associated procedures that can be validly and effectively applied on a step-by-step basis to all major classes of Air Force systems. The technical elements are addressed to fundamental aspects of the system and cost effectiveness management implementation process. These aspects are:

- the formulation of effectiveness criteria
- the evaluation of effectiveness
- the assurance of effectiveness progress and achievement

The system and cost effectiveness technology is broad and complex. It encompasses and operates on diverse, but complementary, technologies and engineering disciplines. An authoritative perspective and a basic understanding of the technology by Air Force and contractor management-level personnel are vital prerequisites for its valid application. The manual is designed to provide this penetrating management visibility as well as to establish a technical base for the specialists who are responsible for the creative and innovative application of the technology.

The manual emphasizes technical elements and procedures that are consistent with technical activities common to current development, procurement, and specification practices of system developers. For example, while it is expected that the system effectiveness parameter will be introduced into top-level system specifications as a new, specialty parameter which measures the collective contribution to the system of its critical functional and specialty technical performance parameters, its introduction is not expected to change the current practice of separately specifying and evaluating these system parameters. Furthermore, the analytical techniques, procedures, and data sources detailed in this manual will be readily recognizable by managers of any of the multi-specialty disciplines of the applied science of systems engineering as being congruous with current technical activities. It is the formalizing, restaging, and redirecting of these related technical activities to obtain an optimum balance of technical performance, schedule, and total cost that is the challenging and creative goal of the system and cost effectiveness management implementation process.

The formal implementation of the effectiveness management process will facilitate the transfer and cascade of consistent and critical system information and decisions from one phase of the system management process to another. For example, the results of gross trade-off studies performed on critical system parameters during the Concept Formulation phase as part of a gross effectiveness analysis will be available for expansion and refinement during the Contract Definition phase. Consequently, an additional purpose of the manual is to ensure the formalizing and availability of this continuum of objective, system-level information and decisions throughout a system's life cycle.

In principle, it is the objective of the system and cost effectiveness technology to determine the interactive influence of the array of system functional and specialty technical parameters. While current knowledge may not support an in-depth analysis of all such interactions, it is the further intention of the manual to provide visibility of the pertinent technical considerations and, where feasible, means for determining the quantitative effects. Therefore, the effectiveness elements and procedures described in the manual are intended to be unrestrictively and selectively applied, with alternate techniques to be developed and used if existing data do not fully support the application of these elements and procedures.

1-3 USE OF MANUAL

To accommodate a wide readership within Air Force activities and industrial concerns, and to facilitate technical continuity, understanding, and ease of usage, implementation and formating features have been incorporated. Some of these are chapter summaries, military management phase orientation, technical management guidelines, specialized application guidelines for specific classes of Air Force systems, and an example illustrating the implementation procedures.

Chapter Summaries

Each chapter begins with a summary. This will allow the users to obtain rapidly a broad perspective of the technical elements and procedures involved in the implementation process. Also, a segmented flow chart is included for each effectiveness element described to provide technical continuity and to summarize input-output information flow.

Phase-Oriented Structure

The manual is oriented to the military management phases of Concept Formulation, Contract Definition, and Acquisition. The effectiveness management implementation activities applicable to each of these phases are detailed and integrated with the phase-related system program management procedures delineated in AFSCM 375-4 and the systems engineering management procedures of AFSCM 375-5. A general knowledge of these procedures is necessary for a full technical understanding of the interactions and complementations of the effectiveness management process with the system program and systems engineering management processes.

Technical Management Guidelines

The implementation of the system and cost effectiveness technology is a Government and contractor participating development, with each of the parties having specific primary responsibilities for its execution. Accordingly, technical program management guidelines are provided in the following areas of responsibility:

Government

- The determination and specification of the appropriate system and cost effectiveness measures
- The establishment and specification of the data needed to document, and to provide visibility and confidence of, overall system progress towards meeting technical goals and requirements
- The specification of the required technical analyses for credible and defensible effectiveness evaluations

Contractor

- The implementation of the effectiveness process
- The establishment of sufficient and valid data sources with maximum utility for effectiveness evaluations
- The establishment of organization, management, and data feedback plans for effectiveness evaluations and dynamic monitoring of progress towards achievement of effectiveness objectives

Specialized Application Guidelines

General procedures applicable to multi-classes of Air Force systems are provided for each technical element of the effectiveness implementation process for each system management phase. These general procedures require a technical translation for each specific application, to accurately represent the technical characteristics of the system and the circumstances surrounding its development and use. Accordingly, a chapter is included in the manual of specialized application guidelines useful for the formulation of effectiveness criteria and for the effectiveness evaluation of specific classes of Air Force systems.

Example of Implementation Procedures

An example is presented in Appendix A to demonstrate and illustrate the effectiveness technical elements and procedures described in the manual. The example addresses the effectiveness formulation and evaluation process for the Concept

Formulation Phase as applied to a transport aircraft system with multiple mission objectives. The example preserves and illustrates the step-by-step sequence of activities for this phase described in Chapter 3. An extension of the example to illustrate the procedures described in Chapters 4 and 5 for the Contract Definition and Acquisitions Phases involves the incorporation of additional complexities, such as design details and other effectiveness activities, and then iterating the basic procedures covered in the example. In consideration of the useful value of a simple example, these complexities are not introduced.

System/Cost Effectiveness Notebook

Since the manual is designed to provide a broad overview of the technical elements and procedures associated with the effectiveness management implementation process, specific technical concepts, methodologies, and data useful for effectiveness analyses are not expanded in detail herein. Such detail information useful to technical specialists responsible for conducting effectiveness analyses and application of the technology is contained in the System/Cost Effectiveness Notebook, RADC-TR-68-352, a document directly applicable as a technical supplement to this manual.

1-4 ABBREVIATIONS AND DEFINITIONS OF TERMS USED

ABBREVIATION

AAE - Aerospace Ancillary Equipment
ADC - Air Defense Command
AFLC - Air Force Logistics Command
AFSC - Air Force Systems Command
AGE - Aerospace Ground Equipment
AVE - Aerospace Vehicle Equipment
CDP - Contract Definition Phase
CDR - Critical Design Review
CEI - Contract End Item
CFP/TDP - Concept Formulation Package/Technical Development Plan
FACI - First Article Configuration Inspection
FOM - Figure of Merit
MGE - Maintenance Ground Equipment

OGE - Operating Ground Equipment

PBS - Program Work Breakdown Structure

PDR - Preliminary Design Review

PSPP - Proposed System Package Program

RAD - Requirements Action Directive

RAS - Requirements Allocation Sheet

RDT&E - Research, Development, Test, and Evaluation

RFP - Request For Proposal

ROC - Required Operational Capability

SAC - Strategic Air Command

SDD - System Definition Directive

SOW - Statement of Work

SPD - System Program Directive

SPO - System Program Office

SPP - System Package Program

TAC - Tactical Air Command

TAD - Technical Approval Demonstration

TPM - Technical Performance Measurement

WBS - Work Breakdown Structure

DEFINITION

Availability - A measure of the condition of the system at the start of the mission at any point in time.

Accountable Factor - A physical or functional, specialty, or operational design variable influencing one or more top-level system performance parameters. In a general context for any level of system design, it is any input variable influencing one or more output variables or parameters.

Capability - A measure of the ability of a system to achieve the mission objectives; given the system condition(s) during the mission, and specifically accounts for the performance spectrum of a system.

Cost Effectiveness - A measure of the performance value received (system effectiveness) for the resource expended (cost).

Dependability - A measure of the system condition at one or more points during the mission; given the system condition(s) at the start of the mission, and may be stated as the probability that the system will enter and/or occupy any one of its significant states during a specific mission.

Effectiveness Parameter - A parameter such as an availability, dependability, or capability measure directly related to a top-level Figure of Merit measure, usually compositing a set of measurable system performance parameters to which it can be technically traced.

Effectiveness Technical Element - A major, identifiable technical activity of the system and cost effectiveness management implementation process.

Figure of Merit - A measure of system effectiveness pertinent to one or more mission requirements.

Performance Parameter - A physical or functional, specialty, or operational technical parameter normally appearing in Section 3.1, PERFORMANCE, of the system specification, and describing a measurable, terminal characteristic of a system that can be observed.

Specialty Technical Parameter - A performance parameter addressing a specialty engineering discipline, such as the human factor, maintainability, penetrability, reliability, safety/security, survivability, or vulnerability parameter.

System Effectiveness - A measure of the extent to which a system may be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability, and capability. It is a measure of the technical performance value(s) or merit(s) of a system.

Transfer Function - A mathematical representation of a functional cause-and-effect relationship of system performance behavior and is based on physical laws, theoretical and empirical design equations, or probability concepts.

Chapter 2

OVERVIEW OF THE SYSTEM AND COST EFFECTIVENESS TECHNOLOGY

Summary

The system and cost effectiveness technology is applied throughout the life of a system. While the effectiveness parameter has a dominant technical characteristic, the technology is implemented as a subprocess of the system program management process and is interactive with the systems engineering management process. A general overview is presented of the effectiveness management implementation process and its integration with these processes which are detailed in AFSCM 375-4 and AFSCM 375-5, respectively. The interactions of the three processes are summarized in time-phased networks for the Concept Formulation, Definition, and Acquisition Phases of systems management. Technical goals of the system and cost effectiveness activities are highlighted for these phases, and a compendium of the activities, their purposes, and their use is provided. The general concept of system and cost effectiveness measures to provide objective criteria and continuous management visibility for critical system selection, development, and operational decisions is described. Figures of Merit as measures of system effectiveness also are described, including their utility during each phase of systems management and their general applicability to different system levels.

2-1 GENERAL

The technical and management activities of the system and cost effectiveness technology are integral elements of the Air Force system program management and systems engineering management procedures described in AFSCM 375-4 and 375-5, respectively. The general contributions of the effectiveness technology to both processes are described in these documents. The specific manner in which this technology can be implemented on a time-phased and practical basis for multi-classes of Air Force systems has been the subject of major Air Force development activities in recent years. To a large extent, the content of this manual represents the results of these activities. General and specific procedural guidelines are prescribed for the implementation of the system and cost effectiveness management process. In principle and in practice, these guidelines are designed to be non-duplicative of existing procedures and activities of the AFSCM 375-4 and 375-5 networks. Additionally, the implementation guidelines are structured to maximize the use of data which are normally generated and required for executing the procedures of these existing networks, thus providing for ease and efficiency of implementation at the technical management level. Because of the broad nature of the system and cost effectiveness technology, a knowledgeable perspective is required of (1) its technical roles, (2) the basic implementation concepts and considerations involved, (3) the interrelations of its specialized and general elements and procedures, and (4) the mutual contributions of the effectiveness, system management, and systems engineering management processes toward the creation and selection of military systems with maximum effectiveness to the using commands. The application of the system and cost effectiveness technology throughout a system's life will provide management visibility and information on a continuous basis for critical development and operational decisions. It is vital, therefore, to implement the effectiveness management process as early as possible in the Concept Formulation Phase to insure that a system will evolve with the best balance of technical performance, schedule demands, and total cost to meet specific mission objectives and/or to improve military force effectiveness. The useful power of the effectiveness process, especially the effectiveness analysis activity, will diminish if initial implementation is deferred to a subsequent phase.

2-2 INTEGRATED SYSTEM AND COST EFFECTIVENESS AND SYSTEMS MANAGEMENT NETWORKS

The system and cost effectiveness process with its technical elements and procedures integrates, augments, and lends direction to the technical actions of the system program management and systems engineering management processes. The manner in which this is accomplished on a time-phased ba[illegible] is sh[illegible]vn in Fig[illegible] 2-1, 2-2, and 2-3. These integrated networks provide a gene[illegible] [illegible]ime and technical dependencies of the three processes during th[illegible] Cor[illegible] [illegible]on, Definition, and Acquisition Phases of systems mar[illegible]nt. [illegible] he effectiveness, system program, and systems engineeri[illegible] [illegible]ed will vary from one program application to another. The a[illegible] [illegible] process are specifically related to the AFSCM 375-4 and [illegible] [illegible]ities in the manual. However, comparable relationships exist, and [illegible] [illegible]lished, between the effectiveness process and any well-disciplined and [illegible] [illegible] program and systems engineering management effort, since only univers[illegible] [illegible]f activities have been included in the networks and expanded in detail in the man[illegible]. Additionally, the effectiveness process shown relates principally to the system effectiveness portion of the system and cost effectiveness technology, namely the aspect of the technology that provides visibility of technical performance adequacy as contrasted to cost performance. This is not to be interpreted as an exclusion of cost performance in the overall analysis, but an emphasis of the system effectiveness technical elements and procedures because of their complexity, their cross-process interactions, and their vital contributions to the achievement of technically efficient military systems. From a technical and management viewpoint, the separately shown effectiveness process can be considered as a prominent sub-network of the systems engineering management network with overlaps into the system program management network.

The system and cost effectiveness process is dynamic in nature, increasing in scope and utility as a system progresses from concept formulation through acquisition and operational turn-over to the using command or agency. During the Concept Formulation Phase, the activities of the process are primarily directed towards:

- The definition of the mission in terms of quantifiable, specific objectives and anticipated mission conditions expected to influence system performance.

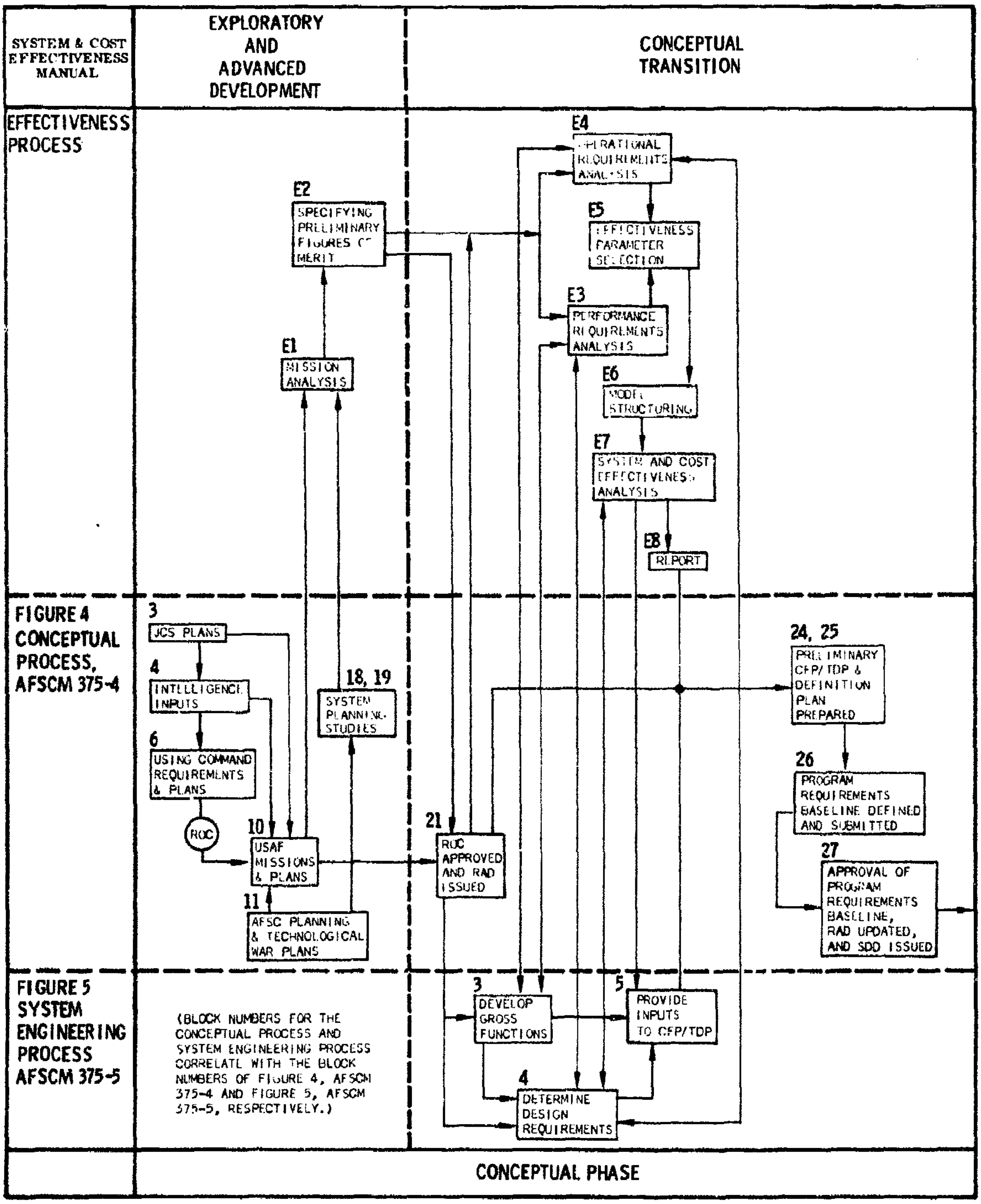
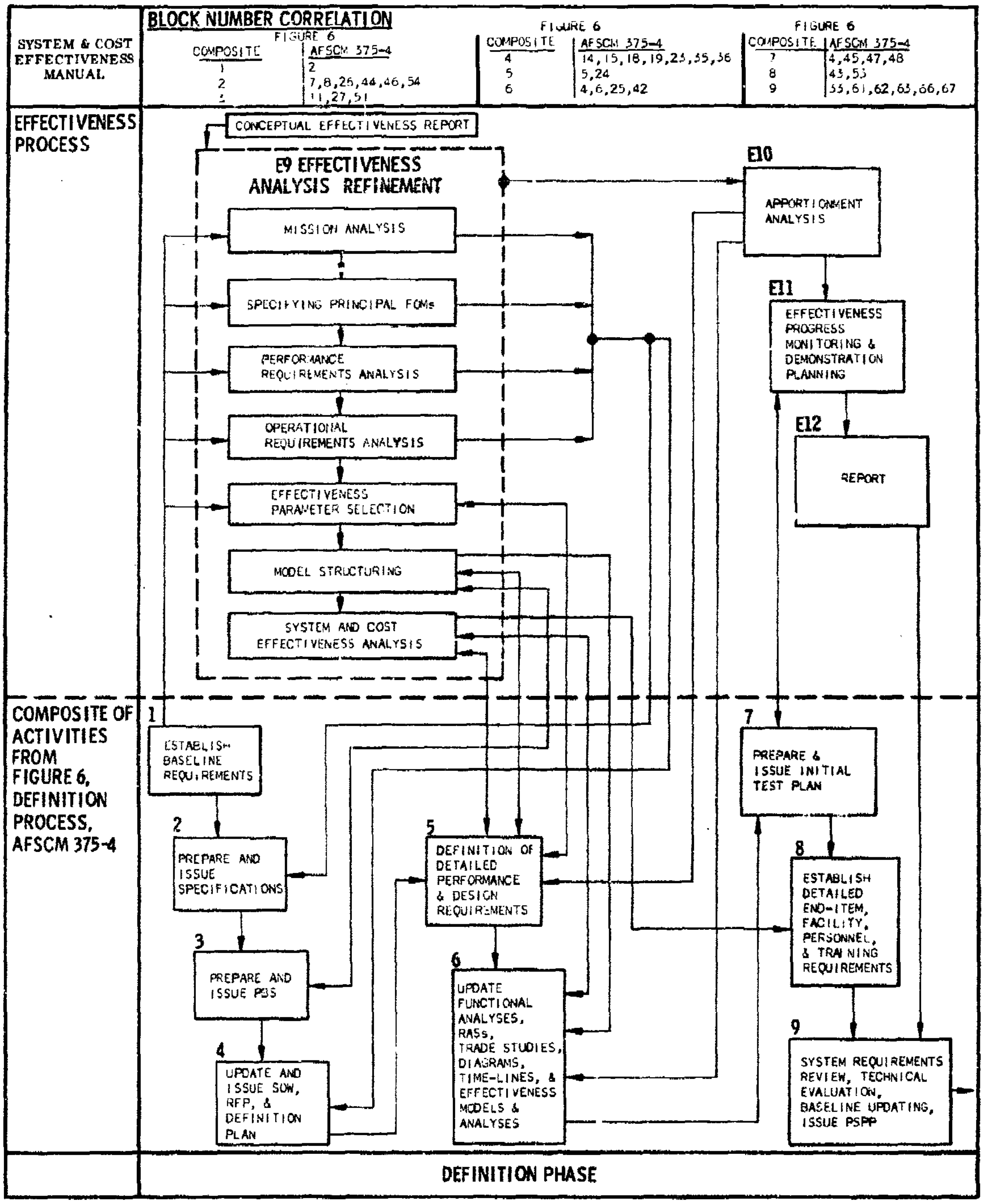


Figure 2-1	Integrated System and Cost Effectiveness Process for Concept Formulation Phase	Page 2-4



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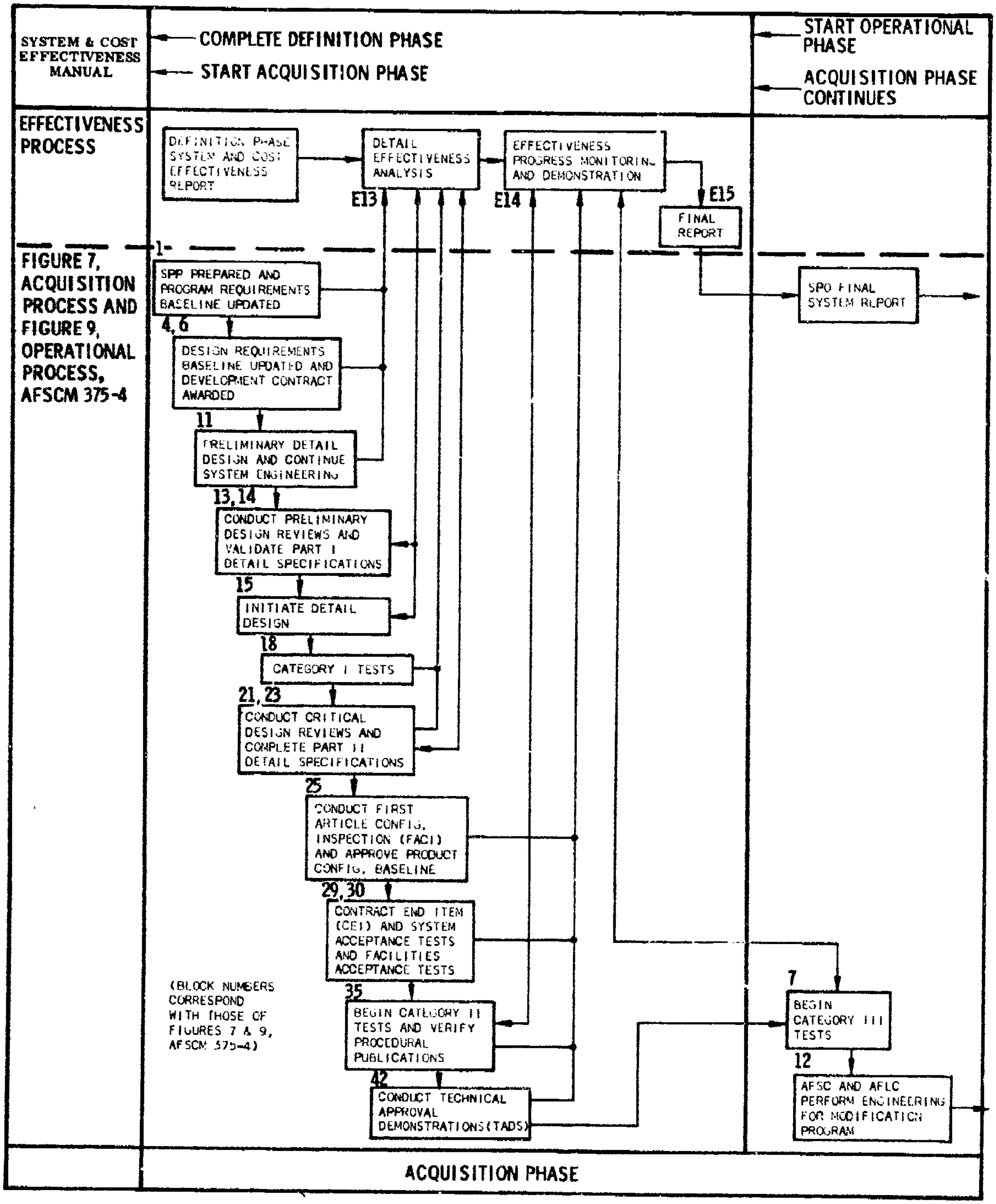


Figure 2-3	Integrated System and Cost Effectiveness Process for Acquisition and Operational Phases	Page 2-6

- The formulation of broad effectiveness criteria, including preliminary Figures of Merit and cost effectiveness measures, to provide a comparison and evaluation basis for the creation and selection of the best system concept(s).
- The gross identification of system performance parameters expected to critically influence system effectiveness.
- The structuring of a gross analytical model for use in effectiveness analyses.
- The system and cost effectiveness analysis of the candidate concepts to factually establish their technical ability and economy to meet military needs, the degree of technical and resource risks involved, and the critical design areas expected.
- The reporting of the analysis rationale and the criteria formulation and evaluation results.

During the Contract Definition Phase of systems management, the system and cost effectiveness process is primarily directed towards:

- The establishment of quantitative system and cost effectiveness measures for each mission objective. Each system effectiveness measure is denoted as a principal Figure of Merit.
- The apportionment of the Figures of Merit. At the top system level (e.g., a military force structure consisting of one or more major systems, such as a strategic aircraft Wing composed of an air-to-ground missile system, a bomber aircraft system, and a ground support system), Figures of Merit can be defined and allocated to each type of constituent system to represent a system's particular contributions to each of the mission objectives. Additionally, an apportionment of the first-level, system Figures of Merit can be accomplished by translating the Figures of Merit into subsystem Figures of Merit or limiting values on the functional and specialty performance parameters of the system. A further extension of the apportionment process to the design accountable factors with critical influence on these system parameters can then be accomplished as design details permit.
- The establishment of system and cost effectiveness models and submodels to provide the analytical analog of the influence of system parameters and accountable factors on the effectiveness measures.

- The determination of data availability for the required analyses, and the identification of the data sources.
- The identification of the system parameters and their first-level accountable factors critical to effectiveness, and definition of their sensitivity and functional cause-and-effect relationships.
- The analysis of system effectiveness for each feasible design configuration or design approach to determine its current effectiveness and predicted effectiveness growth potential within schedule constraints.
- The analysis of cost effectiveness for each feasible design configuration or design approach to determine total system cost, including development cost, acquisition cost, and operational cost associated with manning, operating, maintaining, and logistically supporting the system.
- The formulation of an effectiveness progress monitoring and demonstration plan.
- The reporting of the defined system and cost effectiveness criteria baseline, analysis rationale, and evaluation results.

With the onset of the Acquisition Phase, the system configuration baseline which is anticipated to provide the optimum balance of performance, time, and cost will have been established. Additionally, the principal Figures of Merit, effectiveness parameters, and critical system performance parameters will have been defined and apportioned, the critical accountable factors of the design identified, and models developed for computing effectiveness measures. During this phase, system and cost effectiveness activities primarily are addressed to:

- The re-evaluation and re-selection of the system performance parameters and their required parameter values affecting the Figures of Merit.
- The refinement of effectiveness models and submodels, including the development of computer simulation or other analysis routines, and the validation and re-examination of assumptions to increase model precision.
- The integration of submodels by the prime/integrating contractor with models of the subcontractor/associate contractors, including the establishment of effectiveness analysis standards and guidelines.

- The reapportionment of effectiveness parameters, system performance parameters, and critical accountable factors as required.
- The identification of accountable factors to the next lower level.
- The analysis of the system configuration to determine current and predicted effectiveness status, and the monitoring of the convergence progress of critical system performance parameters, effectiveness parameters, and Figures of Merit to their targeted values.
- The analysis of engineering changes for effectiveness implications.
- The demonstration of Figures of Merit achievement.
- The final reporting of effectiveness results.

Table 2-1 presents a compendium of the effectiveness technical activities (elements), the principal purposes of the activities, and their main contributions to system program management and systems engineering management activities.

2-3 SYSTEM AND COST EFFECTIVENESS MEASURES

The objective of the Air Force military management process is to develop systems which are optimum in terms of performance capability to meet current and future needs for the resources applied. System and cost effectiveness measures are usable to provide quantitative estimates of how well a system can meet this objective. System effectiveness denotes a measure of the extent to which a system may be expected to achieve a set of specific mission requirements. A Figure of Merit is a measure of system effectiveness pertinent to one or more mission requirements of the set. Cost effectiveness is the measure of system effectiveness relative to resource cost.

The system and cost effectiveness measures are used to provide a composite display of the extent to which an optimum mission-system match is achieved for the resources applied. These measures are versatile indices with multiple decision-making usage

TABLE 2-1 COMPENDIUM OF SYSTEM AND COST EFFECTIVENESS ACTIVITIES

Activity	Purpose	Principal Use
	CONCEPT FORMULATION PHASE	
• Mission Analysis	To define the missions in terms of quantifiable specific objectives and anticipated mission conditions	For inclusion in the RAD and CFP/TDP, for establishing preliminary FOMs, and for updating ROC
• Specifying Preliminary Figures of Merit	To provide a technical comparison and evaluation basis for selection of the system concept with optimum balance of performance effectiveness and cost	For inclusion in RAD and CFP/TDP, for effectiveness analysis of system concepts, and decision criteria for system creation and selection
• Performance Requirements Analysis	To translate mission parameters to gross system functions and system performance requirements	For analyzing basic mission/system relationships, for documenting initial effectiveness decisions, for establishing system performance parameters critical to the preliminary FOMs, and for inclusion in CFP/TDP
• Operational Requirements Analysis	To translate mission operational requirements to gross system manning, operations, maintenance, and logistic support requirements	For analyzing basic operational/system relationships, for documenting initial effectiveness decisions, for establishing system operational parameters critical to the preliminary FOMs, and for inclusion in CFP/TDP
• Effectiveness Parameter Selection	To define and relate system parameters critical to FOMs	For inclusion in CFP/TDP and for effectiveness evaluations

TABLE 2-1 COMPENDIUM OF SYSTEM AND COST EFFECTIVENESS ACTIVITIES (Continued)

Activity	Purpose	Principal Use
• Model Structuring	To establish mathematical and simulation analogs relating system and effectiveness parameters to FOMs	For inclusion in CFP/TDP and for evaluation of system and effectiveness parameters and FOMs
• System and Cost Effectiveness Analysis	To evaluate overall balance of performance, schedule, and cost for each system concept	For inclusion in CFP/TDP, for highlighting critical effectiveness design problems and risks as criteria for system comparisons, and for justification of system selection
• Report	To provide compendium of effectiveness formulation and evaluation results and rationale	For inclusion in CFP/TDP, for updating of the RAD, and for preparation of Definition Plan
	CONTRACT DEFINITION PHASE	
• Effectiveness Analysis Refinement	To update, refine, and extend the activities previously initiated in CFP	For guiding trade-off studies in shaping design solutions, for guiding parameter tracking and demonstration planning, for highlighting critical design problems and technical/cost risk areas, and for inclusion in the PSPP
• Apportionment Analysis	To establish traceability and to define allocations of system and subsystem functional and specialty performance parameters	For inclusion into system and detailed CEI specifications

TABLE 2-1 COMPENDIUM OF SYSTEM AND COST EFFECTIVENESS ACTIVITIES (Continued)

Activity	Purpose	Principal Use
• Effectiveness Progress Monitoring and Demonstration Planning	To define the essential system parameters and their expected convergence profile which are to be tracked, and the parameters to be demonstrated	For preparation of the PSPP, for Category II and III and TAD test planning, and for providing current visibility of progress during Acquisition
• Report	To provide compendium of the updated, refined, and extended effectiveness analysis results	For updating of the TDP and for preparation of the PSPP and other baseline documents
	ACQUISITION PHASE	
• Detail Effectiveness Analysis	To provide current and predicted estimates of system and cost effectiveness on a continuing basis as significant design details are developed on product configuration, or as performance requirements are changed.	To guide trade-off decisions in shaping detail design solutions, to evaluate current and predicted system and cost effectiveness status as design progresses, and to reapportion effectiveness and system parameters as needed for optimum cost-performance-time balance.
• Effectiveness Progress Monitoring and Demonstration	To provide a current assessment of technical progress in meeting requirements and goals on effectiveness-related parameters and measures.	To provide management visibility of technical progress on effectiveness growth, critical problems and high risk areas requiring timely attention, and demonstrated performance results under operational conditions.

TABLE 2-1 COMPENDIUM OF SYSTEM AND COST EFFECTIVENESS ACTIVITIES (Continued)

Activity	Purpose	Principal Use
• Final Report	To provide the SPO with a compendium of the final effectiveness baseline used for analyses, achieved versus required/targeted effectiveness objectives, and system improvement potentials for effectiveness growth.	To determine whether effectiveness goals have been met, the extent that operational tactics are affected by final results, and validation of areas requiring engineering modifications.

NOTE: See Chapter 1, paragraph 1.4 for explanation of abbreviations.

depending upon the system evolution p' to which they are applied. For example, effectiveness measures are usable for t. ollowing purposes:

Concept Formulation

- Determination of the best system performance and cost mix in terms of a defined standard (e.g., threat, resource, strike capability) during Exploratory and Advanced Development
- Identification of the degree to which innovations should be pursued
- Evaluation of candidate system concepts for selection of the preferred system
- Guide definition of preferred system(s)
- Determination of optimum force level and operational concepts
- Comparison of existing systems with proposed systems

Contract Definition Phase

- Guide trade-off analysis
- Determination of the critical and limiting parameters and priorities in terms of technical and mission objectives
- Evaluation of candidate configurations of the chosen system concept
- Guide definition of operational policies and tactics
- Guide preliminary design activities
- Provide visibility of critical problem and high risk areas

Acquisition Phase

- Guide trade-off and engineering change analysis at detail design levels
- Establishment of design criteria for optimum performance effectiveness
- Guide areas requiring design concentration
- Evaluation of progress in meeting design objectives on an amalgamated basis

Many Air Force systems have more than one mission and will require more than one Figure of Merit. The multi-mission characteristics of some systems are shown in

Table 2-2. Figures of Merit are mission-oriented and relate to the extent that a system can accomplish each of its mission assignments. Effectiveness measures, therefore, should be in the form of narrative descriptions capable of being quantified into Figures of Merit. Technical performance parameters of a system, such as logistics parameters, navigation accuracy, target recognition capabilities, weapon delivery accuracy, range, power, maintainability, vulnerability, reliability, etc., have considerable effects on the mission and are collectively considered in establishing Figures of Merit. Individually, these parameters are insufficient as measures of the overall performance-cost merits of a system in that they cannot be singularly optimized without influencing the other technical parameters of the system.

System effectiveness may be expressed as a function of three (3) effectiveness parameters of availability, dependability, and capability. The following interpretation of these parameters applies in general:

- Availability

  A measure of the condition of the system at the start of the mission at any point in time. Factors influencing availability include the manning, operations, maintenance, and logistic support parameters.

- Dependability

  A measure of the system condition at one or more points during the mission; given the system condition(s) at the start of the mission, and may be stated as the probability that the system will enter and/or occupy any one of its significant states during a specific mission. Factors influencing dependability include the system parameters of reliability, ground survivability, and in-mission repairability and maintainability.

- Capability

  A measure of the ability of a system to achieve the mission objectives; given the system condition(s) during the mission, and specifically accounts for the performance spectrum of a system. Factors influencing capability include functional performance parameters, enemy threats, vulnerability, penetrability, human performance, and safety/security parameters.

TABLE 2-2 EXAMPLES OF MULTIMISSION AIR FORCE SYSTEMS

Multimission System	Mission
Interceptor Aircraft	Enemy Bomber Interception, Crew Training, Combat Engagement, Ferrying
Strategic Bomber	Enemy Target Destruction, Airborne Alert, Crew Training, Ferrying
Tactical Aircraft	Reconnaissance, Close Air Support, Tactical Bombing, Combat Engagement, Ferrying, Loitering
Transport Aircraft	Emergency Deployment, General Transfer of Cargo, Ferrying
Communications Satellite	Transmission of Priority Messages, Transmission of General Messages
Reconnaissance Satellite	Area Surveillance, Point Surveillance
Command and Control	Air Traffic Control, Interceptor Vectoring, Strike Planning

The basic system effectiveness framework is not to be interpreted as restrictive. For a particular application it may be desirable or practical to combine the availability and dependability parameters, such as might be considered for a set of mission assignments recurring in different sequences. For other applications, it might be appropriate to stratify the system effectiveness measure into effectiveness parameter sets other than availability, dependability, and capability, as long as subsequent compositing of the sets will yield the defined Figures of Merit.

Figures of Merit can be established for different system levels, including:

- top-level (e.g., a force structure composed of systems from different system classes, such as an aircraft system, a missile system, a command-control system, and a support system)
- first-level (e.g., a strategic aircraft system consisting of a strategic aircraft and an air-to-ground missile system carried by the aircraft)
- second-level (e.g., an air-to-ground missile system)
- third-level (e.g., an avionics subsystem of a strategic aircraft)

Many development programs involve the improvement of a constituent system of an overall weapon, support, or electronic system. For such situations, second-level Figures of Merit can be established for the system being improved, as long as its assigned mission roles are defined (even in the absence of higher-order integrating Figures of Merit for the first-level and top-level systems).

Chapter 3

SYSTEM AND COST EFFECTIVENESS IMPLEMENTATION FOR CONCEPT FORMULATION PHASE

Summary

The principal system and cost effectiveness criteria formulation and evaluation elements of the management implementation process which can be efficiently and meaningfully accomplished during Concept Formulation for all major classes of Air Force system are described in detail. The effectiveness elements are defined and related in terms of eight step-by-step implementation activities. These are (1) mission analysis, (2) specifying preliminary Figures of Merit, (3) performance requirements analysis, (4) operational requirements analysis, (5) effectiveness parameter selection, (6) model structuring, (7) system and cost effectiveness analysis, and (8) report. The technical nature, purpose, and application aspects of each activity are presented. Additionally, practical, simple, and versatile techniques and methods are outlined for each activity. These techniques and methods have general applicability to all classes of Air Force systems and are responsive to the gross-type of information normally available to conduct the Concept Formulation studies and analyses. Specific procedural implementation guidelines also are presented and summarized for each activity of the effectiveness process. Further, the information needed to implement each activity, and the technical uses of the activity outputs are polarized with respect to other contributing and recipient activities of the effectiveness process and the interfacing system program management (AFSCM 375-4) and systems engineering management (AFSCM 375-5) processes.

3-1 GENERAL

The Concept Formulation Phase of system development projects is the responsibility of HQ USAF. The purpose of this phase is to provide the technical, economic, and military justification and bases for proceeding with the subsequent phases of Contract Definition and Engineering Development. The primary results of the Concept Formulation Phase are documented in a Concept Formulation Package/Technical Development Plan (CFP/TDP). Department of the Air Force Regulation, AFR 80-20, requires that conditional approval for proceeding with engineering development be based on Concept Formulation Phase results that have met the following six prerequisites:

(1) The effort required is primarily engineering rather than experimental, and the technology needed is sufficiently in hand.

(2) The mission and performance envelopes are defined.

(3) The best technical approaches have been selected.

(4) A thorough trade-off analysis has been made.

(5) The cost effectiveness of the proposed item has been determined to be favorable in relationship to the cost effectiveness of competing items on a DOD-wide basis.

(6) Cost and schedule estimates are credible and acceptable.

The early implementation of the system and cost effectiveness management process during this phase will contribute to the achievement of all of the six prerequisites by providing an objective and integrated evaluation of the potentials of proposed system concepts to meet military objectives as defined in documents such as the Required Operational Capability (ROC) and Requirements Action Directive (RAD).

The following implementation steps summarize in general the effectiveness activities required during Concept Formulation:

- Step E1 - Mission Analysis This activity addresses the analysis of mission requirements to define them in terms of quantifiable, specific objectives and operational conditions.

- Step E2 - Specifying Preliminary Figures of Merit This activity provides a technical comparison and evaluation basis for selection of the system concept with the optimum balance of technical system performance effectiveness.

- Step E3 - Performance Requirements Analysis This activity addresses the technical translation of mission requirements and conditions and the preliminary Figures of Merit into gross system functions and performance parameters influencing system effectiveness.

- Step E4 - Operational Requirements Analysis This activity addresses the technical translation of mission operational requirements to gross system manning, operations, maintenance, and logistic support requirements.

- Step E5 - Effectiveness Parameter Selection This activity identifies the gross top-level system performance parameters and accountable factors critical to a preliminary FOM and its effectiveness parameters of availability, dependability, and capability, and establishes their cause-and-effect relationships and sensitivities.

- Step E6 - Model Structuring This activity provides the overall mathematical and/or simulation models for use in numerical effectiveness analysis of the interactive and integral cause-and-effect relationships of accountable factors, system parameters, effectiveness parameters, and Figures of Merit for each feasible system approach.

- Step E7 - System and Cost Effectiveness Analysis This activity provides for the analysis and evaluation of each feasible system approach for an optimum balance of performance and cost. Additionally, the activity provides for each competing system approach current and projected Figure of Merit estimates to be used as comparative selection criteria for management decisions, leading to the system description with optimum effectiveness.

- Step E8 - Report This activity provides the Air Force technical activity with a compendium of the effectiveness criteria formulation and evaluation results to support program decisions and for inclusion in the RAD revision and CFP/TDP document to be issued at the end of the Conceptual Transition Phase of Concept Formulation.

3-2 MISSION ANALYSIS STEP E1

General

The initial step of the effectiveness criteria formulation and evaluation process is the mission analysis. This involves the preparation of a description which generally and specifically defines the mission objectives and operational conditions anticipated to influence the successful accomplishment of the mission.

Procedure

The description of the mission is to include both general and specific mission objectives. The general objectives are intended as a gross summary of the functions and purposes of the mission. The specific objectives are to further define the general objectives of the mission, and are to be meaningfully stated in unequivocal and measurable terms. Specific objectives should have the following descriptive characteristics:

- They communicate the mission intent. The best stated objectives are ones which minimize alternate interpretations of the specific mission goals.
- They describe the specific, measurable and observable terminal behavior required of a system which is acceptable as evidence that the system can achieve the mission objectives.
- They are mutually exclusive in that one specific objective does not encompass any other objectives in part or in whole. This allows for trade-off decisions on independent objectives and eliminates possible double counting (in the effectiveness sense).

- They refer to mission performance goals of the highest degree of importance, thereby providing a common frame of reference for (1) the establishment of top-level and first-level system performance criteria, and (2) the formulation of unambiguous effectiveness measures.

The set of specific mission objectives provides the focal point for the establishment of system-level functions, the determination of system performance parameters required for these functions, and the formulation of system and cost effectiveness measures to be accomplished in a later step of the effectiveness process.

The operational conditions under which the mission is to be performed is a necessary part of an overall identification of mission objectives. General and quantitative descriptions are required of the mission conditions expected to significantly influence system performance, including:

- The kinds, magnitude, and probability of enemy threats and enemy countermeasures expected to be present as of a specific current date and five years in the future for the wartime mission.
- The system survival requirements under battle and peacetime operational levels of shock, temperature, radiation, and similar natural environments.

During Concept Formulation, specific requirements associated with the mission objectives and conditions are progressively refined, especially the quantitative level of mission conditions expected and the terminal performance behavior required of a system. Where necessary, these requirements must be postulated at the onset before any effectiveness analysis is to be conducted. Otherwise, unrealistic and ambiguous results will be obtained and will invalidate system selection decisions, since the analysis would be based on unspecific, indefinite objectives and conditions which are subject to interpretation.

Information Flow

Normally, the ROC document will provide the basic information for the mission analysis activity of the effectiveness formulation and evaluation process. The ROC will contain general mission objectives and conditions, as well as any specific objectives and conditions that may have been confirmed. Additional mission analysis inputs are the related technical reports of system studies which may have been issued previously by AFSC and using commands.

The mission analysis activity provides the basic inputs to the performance requirements analysis, the next effectiveness criteria formulation activity. Results of the mission analysis are to be progressively updated during the Concept Formulation Phase for inclusion in the CFP/TDP and updated RAD to be prepared at the conclusion of the phase. Coordination, therefore, is required between the AFSC and the using commands to more specifically define the mission objectives and the conditions for inclusion in the RAD.

The basic information network for the mission analysis activity is shown in Figure 3-1.

3-3 SPECIFYING PRELIMINARY FIGURES OF MERIT STEP E2

General

The mission analysis defines the mission in terms of specific objectives and operational conditions. The general measure of the extent to which a system may be expected to achieve this set of performance objectives is a function of the effectiveness parameters of availability, dependability, and capability, and is designated as system effectiveness, with the measure of system effectiveness pertaining to one or more of the mission objectives during this phase defined as a preliminary Figure of Merit (FOM).

Previous conceptual studies of military doctrines, resource availability, and technical feasibility of various operational and system concepts to accomplish the overall mission are relevant to the formulation of the preliminary FOM. Through broad trade-studies and use of operations research techniques, choices of systems or system combinations have been narrowed to a few promising concepts potentially possessing the needed basic capabilities. To a large extent, such information is reflected in the ROC and its supportive studies and, along with the mission analysis results, is the minimum required to formulate a preliminary effectiveness measure to be used as a technical and evaluation benchmark during the Concept Formulation Phase.

Typically, an effectiveness measure will be broad at this point in time since numerical values may not be definable because of the general nature of studies to date. Consistent with the definition of mission objectives, however, it is important that the effectiveness measure also be stated in terms of performance behavior which is observable and

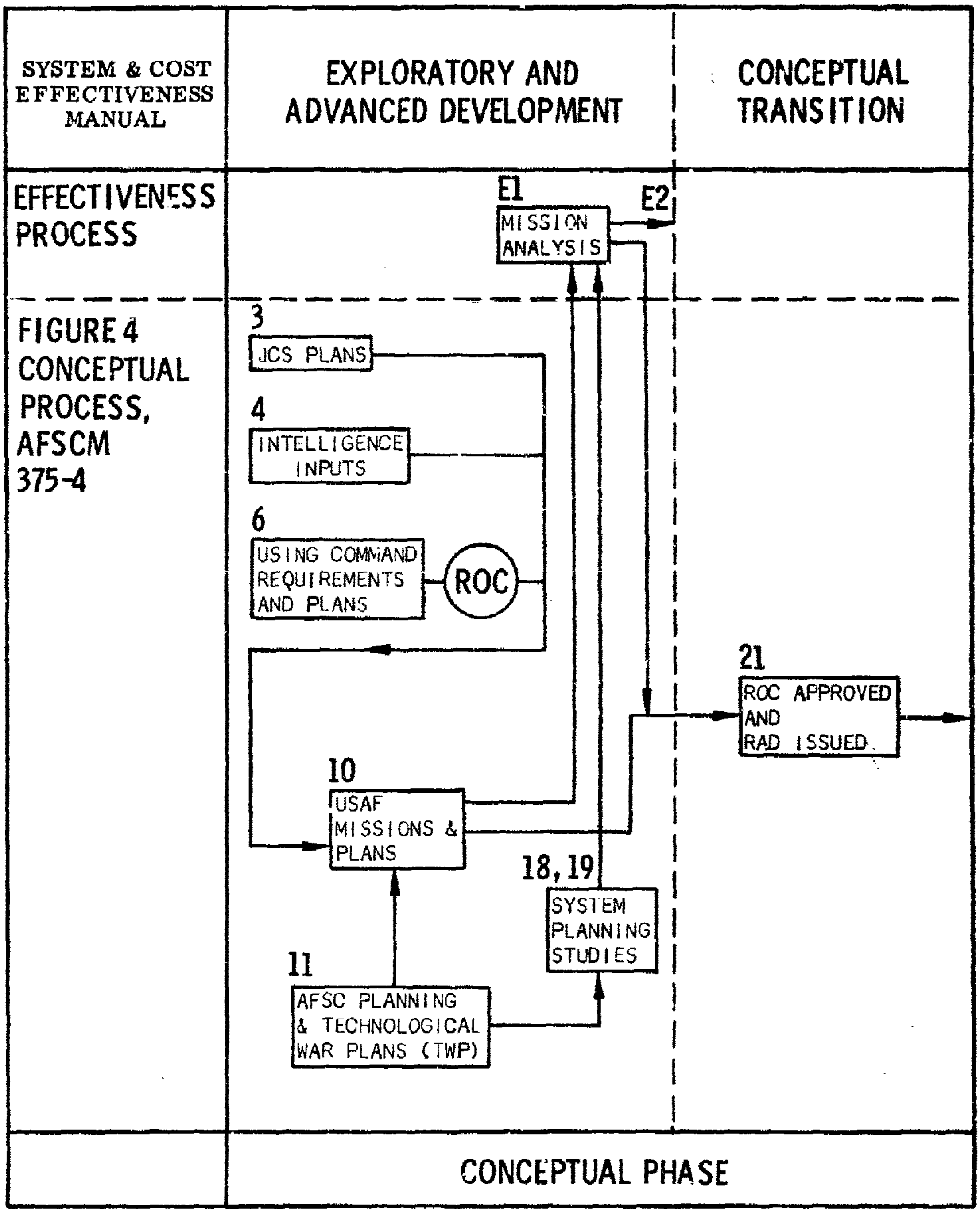


Figure 3-1	Mission Analysis Information Network	Page 3-7

measurable in the candidate systems. An effectiveness measure relates to the net worth or merit of a system to accomplish its assigned mission objectives. As such, it is not fully independent of the system configuration, although in principle it is independent in that it is a reflection of the mission objectives and, therefore, should not be tailored to fit a specific system configuration or make-up which could compromise the mission objectives. As the candidate system concepts with the greatest likelihood of meeting the mission objectives become more fully defined, however, a refinement of the preliminary effectiveness measure is required to reflect numerical objectives and the latest mission requirements for inclusion in the RAD.

The basic purposes of defining a preliminary system effectiveness measure early in Concept Formulation are:

(1) To provide a common criterion of competence based on an objective, per-performance-oriented measure of a system's overall worth in meeting mission objectives for the initial and critical decision of system concept selection.

(2) To ensure a focal performance objective for the continuum of system program, systems engineering, and other disciplinary actions directed at establishing system requirements and more detail concepts.

(3) To provide a common benchmark for continuing effectiveness decisions and evaluations by Government and contractor personnel.

A system's overall role in a mission is the principal criterion for the development of realistic and useful preliminary FOMs. A system may be usable for different types of missions. Such a system will have multiple FOMs associated with it, one for each type of mission that the system is capable of executing. Due to operational considerations such as tactics and countermeasures, a system also may have the capability for employment in different ways to accomplish objectives relating to the same type of mission. For such systems, an additional preliminary FOM should be ascribed to each significantly different way for which a particular type of mission can be executed. Where a large number of ways are involved, a composite FOM addressing the system's adequacy to accomplish the spectrum of ways may be the most practical measure to use. The use of a composite FOM measure also may be equally appropriate for the analogous situation where a large or continuous range of mission outcomes is present for any single way that a particular type of mission can be accomplished.

In general, a ·liminary FOM statement should be based on probability concepts, with a minimum, m· imum, or expected value assigned depending on the extent of system and mission defi· ·ion achieved and the specific mission needs. Further, weighted mathematical combinations of FOMs associated with different missions to arrive at a composite, overall FOM for the totality of missions should be used only under restrictive conditions wherein (1) a relative importance can be validly assigned to each mission, (2) the FOMs to be combined are of the same measurement unit, and (3) the resultant, single FOM does not create an artificial technical and military use situation.

The primary utility of the preliminary FOM (or FOMs) to be established in the Concept Formulation Phase is to provide a technical comparison and evaluation base for conceptual studies. For some applications, a subset of specific objectives or unique capabilities required for improving military force effectiveness could be emphasized. For use in this context, the preliminary FOM may not necessarily correspond to the principal FOM to be developed during Contract Definition, nor be structured as an encompassing, integrated measure of the system's net worth to the mission.

Procedure

The procedure for establishing a preliminary FOM involves the following technical activities:

- Identify from the mission objectives the basic capabilities that the system is to possess and which are to be used as a technical and comparison base for concept selection decisions
- Translate the mission objectives into quantifiable, compositing measures of system performance which are observable
- Identify the kinds and levels of mission conditions which are to apply, assigning minimum, maximum and/or average values as appropriate
- Prepare a description of the preliminary FOM for inclusion in the RAD. Examples of FOMs are listed in Table 3-1.

Information Flow

The primary inputs for preparing the descriptive statement of the preliminary FOMs are the result of the mission analysis. Figure 3-2 shows the information network for the specifying preliminary Figures of Merit activity of the effectiveness process.

TABLE 3-1 FIGURE OF MERIT EXAMPLES

System Class	Mission	Figure of Merit
• Interceptor	The interceptor squadron is to identify and/or destroy assigned target aircraft; the prime mission is to be supported with necessary training missions	(a) Probability of destroying (n) enemy aircraft per engagement (b) Expected targets killed per day by a fixed force (c) Expected number of training missions which can be completed per month
• Strategic Bomber	The strategic bomber is to deliver its payload to an assigned target within prescribed accuracy and then return to base; the prime mission is to be supported with necessary training missions	(a) Probability of destroying (n) targets (b) Probability of (n) bombs on target per aircraft (c) Expected number of training missions which can be completed per month
• Tactical Aircraft	The tactical aircraft is to (1) provide close air support for ground troops, (2) bomb tactical targets, (3) fly reconnaissance, and (4) provide air escort for tactical bombers.	(a) Expected number of sorties which can be accomplished per month (b) Probability of successfully completing a close air support (c) Probability of successfully completing a tactical bombing mission (d) Probability of successfully completing a reconnaissance mission (e) Probability of successfully completing an air escort mission
• Transport	The transport aircraft is to (1) deliver a strategic cargo from origin to destination within a prescribed time, and (2) transport general cargo	(a) Probability of delivering a specified strategic cargo to its destination (ton-miles) within (x) hours

TABLE 3-1 FIGURE OF MERIT EXAMPLES (Continued)

System Class	Mission	Figure of Merit
• Transport (Continued)		(b) Expected time required to deliver strategic cargo (c) Expected number of ton-miles of general cargo transported per sortie (d) Probability of take-off and landing in (x) distance with a specified gross weight
• Space Launch Vehicle	The launch vehicle is to place a given payload into a prescribed orbit within a specified time interval	(a) Probability of placing the payload into orbit
• Communications Satellite	The communications satellite is to (1) transmit high priority messages within a specified time, and (2) transmit low priority during slack time	(a) Probability of transmitting a high priority message within (x) seconds (b) Expected number of low priority messages transmitted per month (c) Expected waiting time of a low priority message (d) Expected number of channels operating at a specified effective radiated power over (n) years (e) Probability that the ground system will operate continuously for (x) period of time and (1) locate an orbiting satellite at a given point in time, (2) transmit commands to, and receive data from the satellite, (3) spatially correlate the data when required, and (4) control and operate the payload

TABLE 3-1 FIGURE OF MERIT EXAMPLES (Continued)

System Class	Mission	Figure of Merit
• Intercontinental Ballistic Missile	The ground-to-ground ballistic missiles are to destroy prescribed enemy targets, given a prescribed sequence of missiles initiated at random times	(a) Probability of destroying a prescribed target of (x) hardness when (n) missiles are targeted on it (b) Expected number of targets destroyed of (x) hardness with (n) or less missiles (c) Probability that the missile can be stored in the silo with all circuits energized for (x) years and no maintenance (d) Probability that a missile can respond to, and meet, a specific mission directive at a random point in time following an alarm condition shall be greater than (y)
• Air Interceptor Missile	The air-to-air missile is to destroy enemy aircraft when launched on a prescribed pursuit path	(a) Probability of destroying an enemy aircraft with (n) or less missiles (b) Expected number of missiles required per squadron to maintain an (x) level of operational readiness
• Air-to-Ground Missile	The air-to-ground missile is to destroy prescribed targets	(a) Probability of destroying an (x) hardened target with (n) or less missiles (b) Expected level of damage to an (x) hardened target with (n) or less missiles (c) Probability of destroying (n) of (m) targets assigned to the squadron (d) Expected number of missiles per squadron required to maintain an (x) level of operational readiness

TABLE 3-1 FIGURE OF MERIT EXAMPLES (Continued)

System Class	Mission	Figure of Merit
• Command and Control	The command and control system is to (1) store, process, and retrieve information for command decision, (2) control traffic of friendly aircraft, (3) detect and track enemy aircraft, and (4) vector interceptors engaging enemy aircraft	(a) Expected information retrieval time (b) Probability of information loss (c) Probability of controlling traffic up to (n) friendly aircraft given no enemy aircraft are being engaged (d) Probability of successfully vectoring intercepts against (n) enemy aircraft
• Warning and Detection	The warning and detection system is to detect and track an airborne or sea-launched object within a prescribed accuracy and a prescribed coverage area	(a) Probability of detecting an object given that (n) tracks are in process (b) Probability of successfully completing a track, given detection (c) Expected number of tracks which can be performed simultaneously within a prescribed accuracy

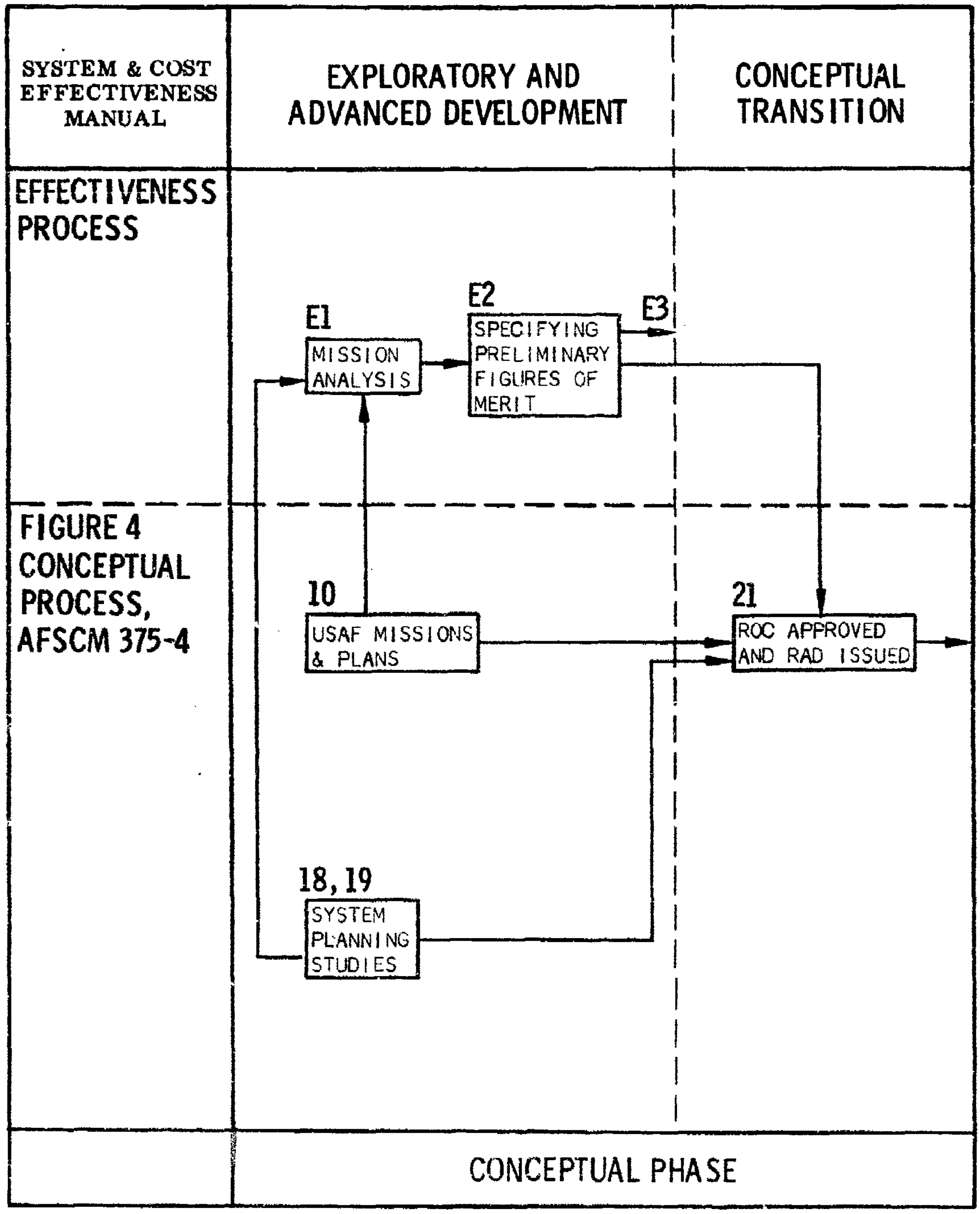


Figure 3-2	Specifying Preliminary Figures of Merit Information Network	Page 3-14

3-4 PERFORMANCE REQUIREMENTS ANALYSIS **STEP E3**

General

The purpose of the performance requirements analysis is to translate the mission objectives and conditions into gross system functions and system performance parameter requirements critical to the preliminary FOM and, thus, the effectiveness of the system. The analysis is best accomplished by the preparation of a performance requirements profile. This profile is a practical method for compositing and analyzing the mission-system relationships influencing mission accomplishment and system effectiveness.

A performance requirements profile is time-phased. It usually consists of a set of tables and matrices that collectively provide an analytical compendium of the quantitative system performance parameters. The primary uses of the profile during Concept Formulation are:

- To establish the basic reference frame for establishing a more specific, analytical description of the preliminary FOMs, and for the subsequent analysis of a system's ability to meet the FOMs.
- To document initial effectiveness decisions for later retrieval, and to reveal where future decisions are required.
- To identify the set of relevant system performance parameters influencing effectiveness for trade-off studies and decisions.
- To provide visibility of the system performance parameter values which are unknown, grossly known, or more precisely known, and, thus, ensure validation of the credibility to be attached to later effectiveness evaluation results.

Separate resolution of each mission is required for multi-mission systems. Also, where a system is intended for multi-mode usage, such as primary, secondary, back-up, etc., or where different combinations of system functions will be utilized, each mode and function combination must be separately portrayed and analyzed.

Relationships of mission objectives to system performance requirements to be quantitatively analysed with a performance requirements profile include the following:

- Mission objectives to mission performance requirements.
- Mission performance requirements to overall gross system functions.
- Overall gross system functions to gross system performance parameters, including functional/physical parameters and specialty technical parameters of reliability, maintainability during mission, survivability, safety, human factors, etc.
- System counter threat or neutralizing capabilities for the kinds and levels of mission conditions expected.

During Concept Formulation, the profile is to be grossly portrayed at the top-level in a simplified form, and is to be extended to the first level of design if details permit. A further extension to the second level is not required. In the development of the profile, it is desirable to quantitatively define as many of the relationships as possible. Those relationships for which values cannot be practically assigned at this point must be handled qualitatively, but should be kept to a minimum.

Procedure

The following steps are necessary to a performance requirements analysis:

- Identification of mission performance requirements and the specific kinds and levels of conditions surrounding the mission, including their probability of occurring
- Identification of overall system functions required for each candidate system concept to realize the mission performance requirements
- Identification of top-level system design performance parameters and constraints imposed on those parameters by the mission requirements, mission conditions, and system functions

- Identification of the maintenance concepts applicable to a mission assignment, including capability requirements for correction of malfunctions, over-ride, and correction of battle damage through permanent or temporary repairs (e.g., in-flight or ground controlled adjustments)
- Preparation of matrices and/or tables of the relationships. Table 3-2 presents a typical listing of mission requirements, mission conditions, and system performance functions and parameters for inclusion in a performance requirements analysis. The listing addresses all classes of Air Force systems and a typical information availability situation. Therefore, all of the listed requirements, conditions, functions, and parameters will not necessarily apply to any one system or system class.

Information Flow

The basic input data required for the performance requirements analysis are:

- Mission objectives, requirements, and conditions, and their values, from the mission analysis activity and the RAD.
- The preliminary FOMs, the related objectives represented by the FOMs, and the rationale for FOM selection from the RAD and/or from the effectiveness activity of specifying preliminary Figures of Merit.
- The time-sequenced, proposed system functions, the Requirements Allocation Sheets, Trade Studies, and Time Lines from the Develop Gross Functions activity of the systems engineering management process defined in AFSCM 375-5.
- The initial top-level system design/performance requirements and their values, from the Determine Design Requirements activity of the systems engineering management process, also defined in AFSCM 375-5.

The results of the performance requirements analysis will be used to establish the top-level system performance parameters for each system that are critical to the

TABLE 3-2 TYPICAL MISSION REQUIREMENTS, MISSION CONDITIONS, SYSTEM FUNCTIONS, AND SYSTEM PERFORMANCE PARAMETERS

Mission Requirements

- Destination and path
- Accuracy
- Payload
- Envelope
- Range
- Kill probability
- Coverage
- Life
- Rate
- Weight and size
- System effectiveness
- Safety/Security
- Communications
- Training

Mission Conditions

- Enemy threats and counter-measures
- Natural environments
- Reaction time

System Functions

- Control and stabilization
- Propulsion
- Communications
- Command
- Detection and identification
- Acquisition
- Track
- Cruise
- Climb
- Payload delivery
- Combat
- Navigation
- Data processing
- Terrain avoidance
- Land
- Intercept
- Engage
- Reconnaissance
- Ferry

System Performance Parameters

- Trajectory
- Weight
- Accuracy
- Envelope
- Information rate
- Payload dynamics
- Range
- Take-off and landing distances
- Refueling characteristics
- Speed
- Thrust
- Weapon capacity
- Maintainability during mission
- Reliability
- Survivability
- Vulnerability
- Penetrability
- Safety
- Power
- Rates
- Noise
- Human performance
- Lethality
- Stability

preliminary FOMs. Upon an integrated analysis of the top-level system design/ performance requirements later in the effectiveness process, the best combination of parameter values for a maximum effectiveness can be determined. These values then can be used to confirm or update the initial values for inclusion in the CFP/TDP.

Figure 3-3 illustrates the basic information network for the performance requirements analysis.

3-5 OPERATIONAL REQUIREMENTS ANALYSIS Step E4

General

The technical concepts and parameters for manning, operating, maintaining, and logistically supporting a weapon, electronic, or support system have a major influence on the effectiveness of the system to respond to mission directives and to accomplish mission assignments of the Air Force (TAC, ADC, SAC, AFLC, etc.). These concepts and parameters are the basis by which the using commands can plan tactics, readiness exercises, and training to fully utilize the capabilities of the system. Mission requirements and system performance parameters have been defined by the performance requirements activity of the previous step in the effectiveness process. These parameters are normally associated with the effectiveness parameter sets of dependability and capability. To complete the definition of the parameter sets which can influence the effectiveness of a mission, another set of performance parameters must be defined, and the associated mission-system interrelationships analyzed. This set consists of the system operational parameters. Consistant with the performance requirements analysis, the purpose of the operational requirements analysis is to translate the mission operational requirements into needed system concepts and dominant manning, operations, maintenance, and logistics parameters contributing to system effectiveness.

The availability parameter of system effectiveness, by encompassing the manning, ground operations, maintenance, and logistics characteristics of a system, is a measure of the readiness or condition of the system at the start of the mission at any point

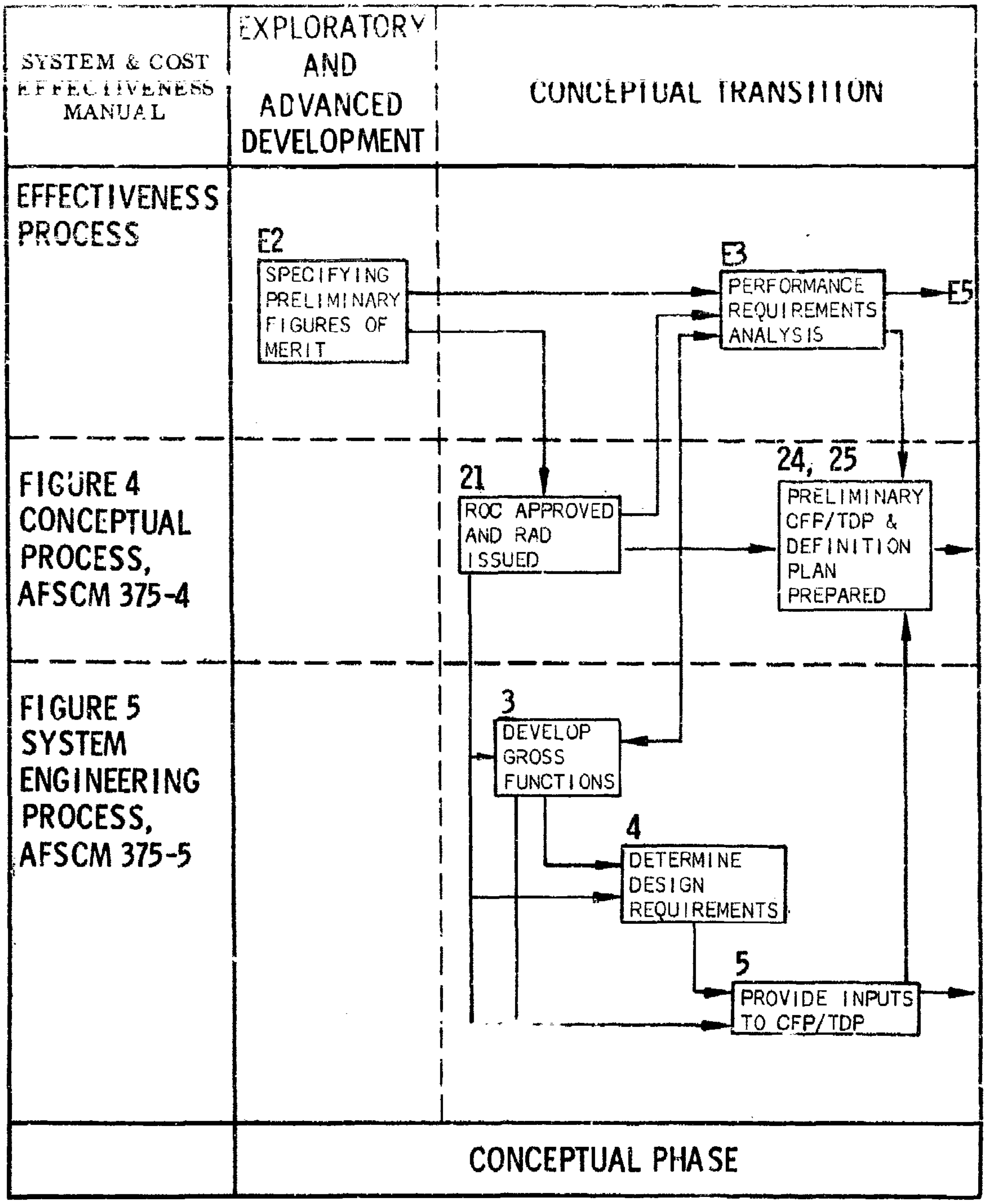


Figure		Page
3-3	Performance Requirements Analysis Information Network	3-20

in time. For recurring type missions (e.g., air escort missions, tactical air-to-ground missions, weapon delivery missions of a squadron of tactical aircraft, warning and detection missions, etc.), the effectiveness parameter of availability is also dependent upon the mission system reliability parameter of the effectiveness dependability parameter, since the frequency and duration of needed ground maintenance and repairs will be influenced by the kinds and magnitude of failures and malfunctions expected to occur during mission assignments.

An integrated approach to the analysis of operational parameters is required to collectively and quantitatively identify and define the principal system parameters contributing to availability, and hence to system effectiveness. This is a technical necessity because of the interrelationships among the operational parameters. The results of this integrated approach will provide useful design guidelines to system developers as well as simplified information for decision making by both logistics and operational planners relative to obtaining maximum utilization of the system at minimum operational cost.

System operational parameters which are interrelated and provide the basis for performance, time, and resource trade-offs, the comparative analysis of alternate system concepts, and the evaluation of different operational policies, include:

- Maintenance
- Employment
- Deployment
- Transportation
- Personnel
- Base and depot support
- Training
- Test and activation

As with the performance requirements analysis, the operational requirements analysis is best accomplished by the preparation of a profile, with the basic uses of the profile being identical to those for the performance requirements profile.

Procedure

The following is a procedure for accomplishing an operational requirements analysis:

- Identification of the operational requirements for the mission in terms of specific, quantifiable objectives and constraints.
- Establishment of a mission-level measure of operational performance which can be commonly used for all candidate systems concepts. The measure is to reflect the operational availability of the system for a specific mission assignment, and is to account for the integrated contribution to the total operational turnabout and reaction time span by the system's manning, operations, maintenance, and logistic support parameters and assets. Examples of availability measures are listed in Table 3-3.
- Definition of the operational concepts associated with each candidate system approach. Examples of concepts to be defined also are listed in Table 3-3.
- Gross identification of the requirements for system operational parameters such as maintainability, reaction time, and required turnabout time influencing the mission operational requirements, and constraints that the requirements may impose on these parameters.
- Preparation of a composite display of the interrelationships in the form of an operational requirement profile. For the parameters where gross values cannot be established at this point in the Concept Formulation Phase, the values are to be defined later in the effectiveness process. Examples of operational parameters influencing availability also are listed in Table 3-3.

TABLE 3-3 EXAMPLES OF OPERATIONAL AVAILABILITY MEASURES, CONCEPTS, AND PARAMETERS

Availability Measure

- Operational time per a fixed period (e.g., available flight time per month)
- Probability that the weapon can be stored with all circuits energized for (x) years and no maintenance
- In-commision (ready) rate or utilization rate
- Probability of completing turn-about in (t) time or less
- Reaction time

Operational Concept

- Basic Maintenance Policy
- Level and location of maintenance
- Level and location of spares*
- Alert conditions*
- Number of installations, sites, and operating locations*

Operational Parameter

Maintenance Parameter

- Mean and maximum time to repair*
- Mean and maximum time to restore for continuous operation
- Maintenance man-hours per operating hours*
- Time constraints for preventive maintenance*
- Maintenance environment, including facilities, climate, and geographical location
- Probability of maintenance (probability that maintenance will be completed in (t) time or less)
- Type and level of personnel required, by specialty skills*
- First-level spares required, by type and quantity*
- Cost

Employment Parameter

- Critical performance interfaces of the system with other systems to be employed in the mission, including total reaction time, error contribution, survival periods, target identification time, etc.

Deployment Parameter

- Kinds and levels of peacetime-wartime natural environments, including gross estimates of expected wind loading, snow loading, precipitation, temperature, humidity, atmospheric pressure, wind shear, turbulence, vertical gust velocities, energy input from solar radiation, particle mass and energy spectrum, etc., as appropriate
- Special facilities required for system mission readiness state
- Cost

*Depending on the degree of preliminary design and the establishment of operational details during Concept Formulation for a particular application, defensible estimates of these parameters may not be available.

TABLE 3-3 EXAMPLES OF OPERATIONAL AVAILABILITY MEASURES, CONCEPTS, AND PARAMETERS (Continued)

Transportation Parameter

- Cubage
- Special handling facilities (time restraints)
- Cost

Personnel Parameter

- Number of Wing level personnel which may be allocated to the operation and control of the system. This quantitative figure is to be compatible with expected or anticipated changes in Air Force personnel resources*

Base and Depot Support Parameter

- AGE requirements by type*
- Lead time*
- Spares distribution*
- Cost*

Training Parameter

- Cost*
- Special training facilities*

Test and Activation Parameter

- Test and activation equipment mean and maximum time to repair*
- Cost*

*Depending on the degree of preliminary design and the establishment of operational details during Concept Formulation for a particular application, defensible estimates of these parameters may not be available.

Information Flow

The basic input data required for the operational requirements analysis are:

- The operational requirements from the ROC and RAD.
- The preliminary FOMs, the corresponding mission objectives represented by the FOMs, and the rationale for FOM selection from the RAD and/or from the effectiveness activity of specifying preliminary Figures of Merit.
- The proposed system maintenance functions, operational test and activation functions, Requirements Allocation Sheets, Trade Studies, and Time Lines from the Develop Gross Functions activity of the systems engineering management process defined in AFSCM 375-5.
- The initial top-level system design/performance requirements, and their values, from the Determine Design Requirements activity of the systems engineering process, also defined in AFSCM 375-5.

The results of the operational requirements analysis are usable to establish the system operational parameters critical to the preliminary FOMs for each candidate system concept. Upon an integrated analysis of the top-level system design/performance requirements later in the effectiveness process, the best combination of parameter values for a maximum system effectiveness can be determined. These values then can be used to confirm or update the initial values defined in this effectiveness step for inclusion in the CFP/TDP.

Figure 3-4 illustrates the basic information network for the operational requirements analysis. This network is similar to the performance requirements network. At this point in the effectiveness process, an identification has been made of the totality of top-level functional, specialty, and operational system parameters influencing the preliminary FOMs. This is the union of the two sets of information represented by the results of the performance requirements analysis of Step E3, and the operational requirements analysis of this step.

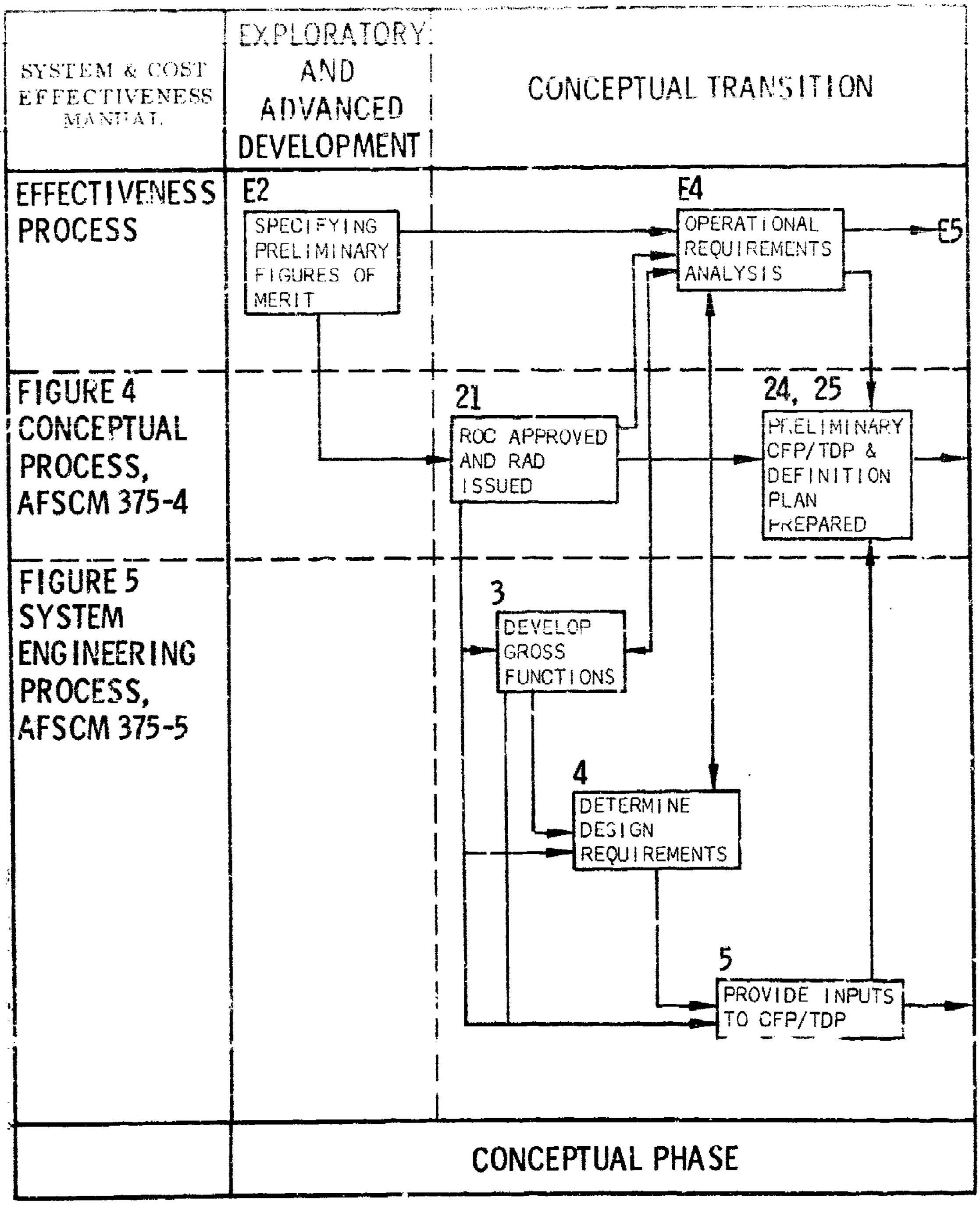


Figure 3-4	Operational Requirements Analysis Information Network	Page 3-26

3-6 EFFECTIVENESS PARAMETER SELECTION $\boxed{\text{STEP E5}}$

General

The performance and operational requirements analysis activities of Steps E3 and E4, respectively, were directed at identifying the total set of mission-related system functions and parameters for each system concept. The results of the analyses provided a broad perspective of the primary mission-system cause-and-effect relationships potentially influencing system effectiveness. The purpose of the effectiveness parameter selection activity is to reduce the total set of effectiveness-related system functions and parameters to a simplified and analytically manageable subset of effectiveness relationships and parameters which are critical to the evaluation of system effectiveness and the preliminary FOMs. Principle technical elements of the effectiveness parameter selection activity include:

- The formulation of criticality matrices
- The identification of critical accountable factors
- The establishment of transfer functions
- The analysis for effectiveness sensitivity

Formulation of Criticality Matrices

Criticality matrices can be used to provide a gross, but visible rating of relative importance of system parameters to each other, and to the FOMs. In the initial formulation of the matrices, rankings are to be assigned based on engineering judgment. This is a necessary beginning step to an eventual resolution of the rankings using the results to be obtained from applying the more objective and scientific technique o. ross sensitivity analysis later in this step.

A criticality matrix should be prepared for each preliminary FOM. The matrix is formed by listing in rows (or columns) the top-level system performance parameters postulated to have a critical effect on the FOM. The critical first-level accountable

factors (design variables) that will significantly influence the range of values for the selected parameters are listed in the remaining dimension of the matrix. A temporary numerical rating is then placed at each applicable intersection of the matrix to represent the criticality of each intersection relative to the other. An accountable factor may influence more than one system parameter, with most parameters having more than one accountable factor. Parameters to be included in the matrix should be those representing top-level functional, specialty, and operational system parameters contributing to the availability, dependability, and capability of the system for the particular preliminary FOM being analyzed.

An accountable factor is critical to a system parameter, and as a corollary, a system parameter is critical to a preliminary FOM, if it is known or suspected to have a potential of causing a significant effectiveness change. This change can arise from the physical and functional characteristics of the design whereby an incremental change in value or precision of an accountable factor results in a corresponding incremental change in the system parameter which it influences. Such directional shifts may occur through instability, accumulation biases, or a deliberate design localizing to a particularly desirable range of values to obtain an optimum performance behavior. An accountable factor also may be temporarily considered critical if its relationship to the parameter is unknown and/or complex to define during this phase, and if its exclusion may cause a crucial error in a system effectiveness analysis.

The assignment of ranking requires an authoritative perspective of the system concept features under consideration. This knowledge normally is available by the time of conceptual transition and includes:

- Knowledge of the gross performance potentials of first-level elements of the system through related experience, broad operations research analyses, and exploratory trade-off/optimization studies, including early simulation analyses
- Knowledge of gross interactions and response behavior, either directly or through interpolations or extrapolations from similar systems

- Knowledge of the system elements or functions representing technological advancements and, hence, areas of high technical risk with major impact on effectiveness.

Identification of Critical Accountable Factors

Accountable factors are the design variables which influence the top-level system performance parameters composited by the availability, dependability, and capability effectiveness parameters of the system. Most accountable factors are quantifiable and, thus, directly usable in a numerical analysis of effectiveness. Nonquantifiable accountable factors also exist for a system design, and include nonphysical and nonfunctional elements such as design reviews, maintenance and checkout procedures, etc. Such accountable factors normally are not usable in a numerical analysis of effectiveness. Thus, only critical, quantifiable accountable factors are of relevance and are to be identified during the Concept Formulation Phase.

All accountable factors have constraints. These constraints are imposed by design considerations such as the state of technological advances, by apportionments of system parameters, and by economic or resource limitations. A constraint on an accountable factor is important only if the margin existing for trade-off analyses is small or is difficult to achieve.

Nature of Transfer Function

Transfer functions are the mathematical representation of system cause-and-effect (input-output) relationships and exist for all system designs. Typical cause-and-effect relationships influencing system performance and, correspondingly, the preliminary FOMs, for which gross transfer functions can be defined during Concept Formulation include:

Cause/Input	Effect/Output
• First-level accountable factors	System performance parameters

Cause/Input (Continued)	Cause/Output (Continued)
• System performance parameters or first-level accountable factors	Effectiveness parameters of availability, dependability, and capability
• Effectiveness parameters, system performance parameters, or first-level accountable factors	Figures of Merit

The mathematical representations are based on physical laws, theoretical or empirical design relationships, and probability concepts, and must be established and used if the potential of a system concept with respect to the defined preliminary FOMs is to be analyzed.

The top-level effectiveness transfer function is the equation which relates an FOM (E) to its system effectiveness parameters of availability (A), dependability (D), and capability (C). This relationship may be expressed as:

$$E = f(A, D, C)$$

where f is a function depending on the nature of a defined preliminary FOM. First-level transfer functions also can be established to relate the effectiveness parameters of A, D, and C to their respective sets of system performance parameters which they integrate, or directly to the critical accountable factors influencing the system performance parameters. An FOM also may be directly related to these factors.

Additionally, design transfer functions can be associated with each lower level that the system functions can be partitioned, with accountable factors identifiable for each level. During the Concept Formulation Phase, gross transfer functions can be constructed based on functional task analyses, extrapolations from similar systems, theoretical and empirical design relationships, probability concepts, and physical laws. Such functions normally will form the basis for mathematical or physical simulation models to be used for determining the interactive influences of the accountable factors on the performance of the candidate system. The simulation process is iterative and converges onto the broad functional solutions which describe the response of the effectiveness parameters and system performance parameters to changes in values or precision of their critical accountable factors.

Gross transfer functions are to be established and documented for each system performance parameter included in the criticality matrices. As a minimum, this should include first-level functions, and is to be extended to second-level functions if design details permit.

Methods For Determining Transfer Functions and Initial Values

System design fundamentally involves determining exactly how the elements of a system are to be connected, what sensitivities are best, the limitations of the system, its output performance capabilities, and the values of input accountable factors required to achieve the desired capabilities. The dimensionality of the design choices available is extensive, because the number of parameters to be fixed is large, their range is broad, and each is affected by many system inputs. The design problem is complicated further because of the statistical properties of the design variables. Each of the system input accountable factors has a range of values, and the system responses to this ensemble of inputs must be determined.

The preliminary design of a system for optimum system effectiveness normally involves finding initial approximations of transfer functions to describe the behavioral, cause-and-effect characteristics of the system for initial postulated or desired values of input accountable factors and output parameters. The synthesis method is a practical procedure for determining transfer functions given this minimum of knowledge. Table 3-4 summarizes the application characteristics of the synthesis method, with a more detail description of the method presented in Appendix B, Part B1.

Analysis For Sensitivity

The formulation and definition of a system concept with maximum effectiveness require a judicious selection of the design value for each critical accountable factor so that an optimum combination of values for the output parameters (system and/or effectiveness parameters) will result. The selection of the best design values will be dependent upon the amount of visibility present on the quantitative influence of each critical accountable factor to its output parameter(s). Normally, the complex transfer functions previously described are used in simulation or theoretical analyses to provide this perspective. During Concept Formulation, however, a need exists for broadly converging onto these quantitative cause-and-effect relationships. Sensitivity functions can be used for this purpose and can be developed as simplified resolutions of the more complex relationships

TABLE 3-4 CHARACTERISTICS OF SYNTHESIS METHOD

Characteristic	Synthesis Method
• Phase normally applicable	Concept Formulation and Contract Definition
• Ease of application	Difficult
• Relationship of variables*	Transfer functions are implicit functions of inputs and outputs
• Information needed to start preliminary design	Minimum amount. Requires knowledge of inputs and outputs. Then find transfer functions
• Input-output expression for linear, time-varying systems	Provided by a superposition integral
• Procedure	Find transfer functions to satisfy superposition integrals. Then find physical characteristics of system which satisfy transfer functions
• Optimizing procedure (example)	Find transfer function such that the difference (error) between each output and the true output is as small as possible, using this transfer function
• Error criterion (example)	(1) minimum time-averaged squared difference or absolute difference, or (2) minimum expected value of squared difference
• Solution method for simple, linear time-varying systems	Determine transfer functions using vector analysis, matrix theory, and Laplace transforms, for example
• Solution method for complex, linear and non-linear time-varying systems	Combination of numerical and analytical procedures using digital computations
• Special technique to facilitate solution for linear, time-varying system	No simple method

*Inputs and outputs normally are in the form of time-functions

expressed by the transfer functions. The sensitivity functions are generated also by simulations or theoretical analyses.

The procedure for generating sensitivity functions involves the following basic steps:

(1) Postulate an initial nominal value, a standard deviation value, and a candidate range of achievable values for all critical accountable factors influencing each output parameter under investigation. These values will normally be based upon the initial broad trade-off studies which established the feasibility of the system concepts, and on the functional analyses performed to establish the system performance parameters required to meet the mission objectives.

(2) With the previously identified critical accountable factors for each output parameter, perform a simple simulation or theoretical analysis of the accountable factors to determine the best value, or the region where potentially the best value may be contained. Use the range of achievable values and the transfer functions established with the synthesis method as the starting point for the simulation or theoretical analysis. For each accountable factor which independently influences an output parameter, vary its value within the candidate range of achievable values, while maintaining all other accountable factors at their postulated nominal value. For accountable factors which have mutual interactions, the same procedure may be followed, except that the effects due to these factors are assessed by a pairwise or otherwise mutual scanning of the values over their preestablished probable range.

(3) Portray the sensitivity of the effectiveness parameter to the range of values for each accountable factor (or sets of factors where interactions are present) by plotting the response value of the parameter for each change in value of the accountable factor. Describe this response with a curve and a simple, approximate mathematical function, which normally will be nonlinear.

(4) Approximate the nonlinear curve or function with a linear curve or function in the region where the best values are present. Mathematical transformations can be used to accomplish this linearization. The linearization of the cause-and-effect relationships is a practical necessity to (a) provide a perspective of the relative criticality of accountable factors to each other, and to the

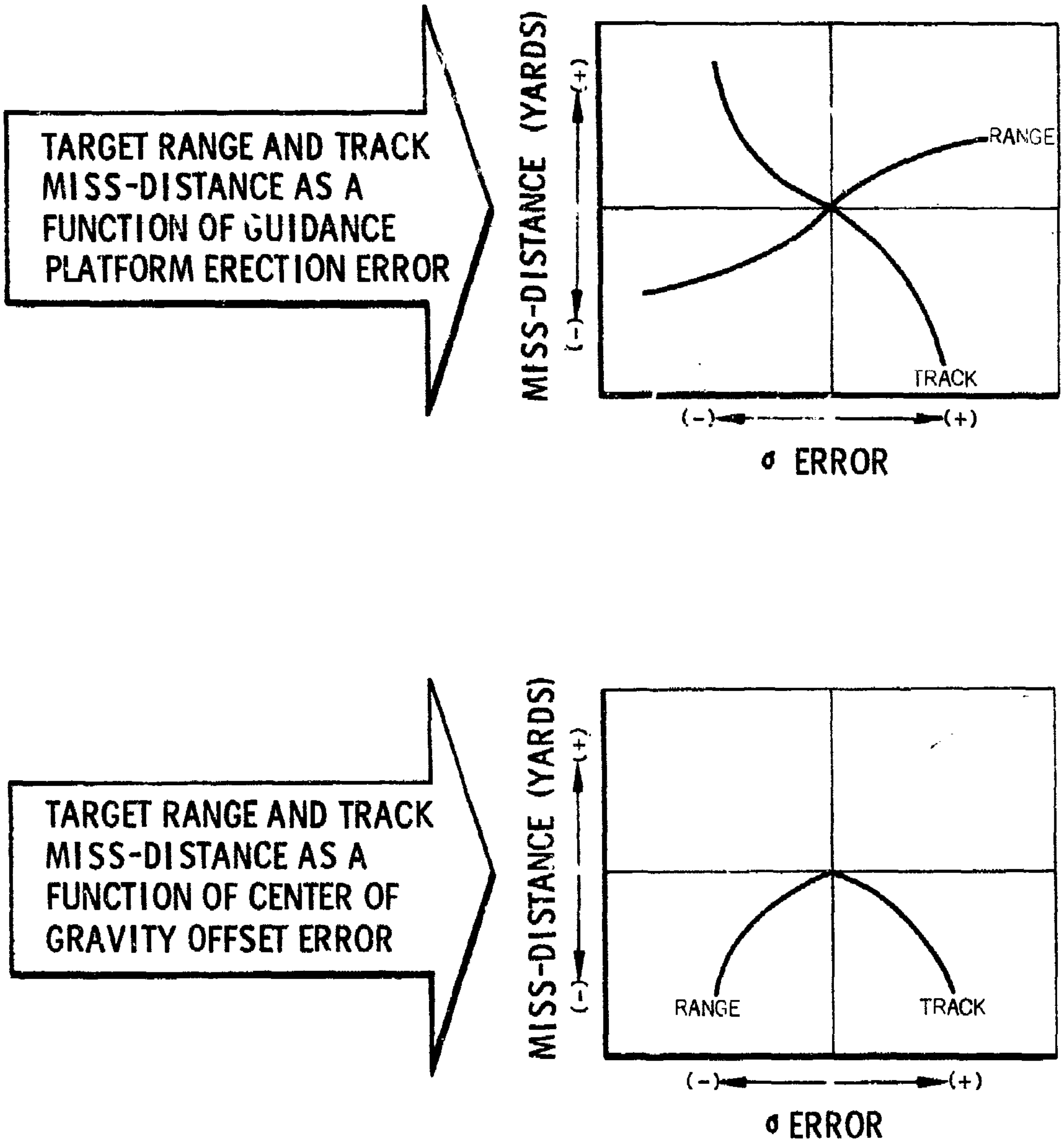


Figure 3-5	Examples of Sensitivity Curves	Page 3-34

effectiveness parameters, (b) facilitate simple analysis of the response distribution for the effectiveness parameter, and (c) eliminate interactive effects. Examples of sensitivity curves are shown in Figure 3-5.

Each sensitivity curve or function thus generated will relate the amount of change in an output parameter for a fixed incremental change of one of its accountable factors. With these visible cause-and-effect relationships, an index can be established of the relative criticality of the accountable factors to each other, and to the output parameter(s) they influence. Additionally, the results of the sensitivity analysis will provide a scientific basis for revision of the accountable factors to be included in the criticality matrix and the preliminary rankings previously assigned. For example, the initial broad rankings can be converted to sensitivity coefficients based on one of the following forms:

- The incremental amount of change in an output parameter expected for a normalized incremental change of an accountable factor (e.g., a standard deviation change). The normalizing of the accountable factor is required because of the difficulty in assessing the relative importance of different increments of change for accountable factors of different measurement units.
- The amount of change required for each accountable factor for a fixed increment of improvement in the output parameter (e.g., a .05 increase in its probability measure).

Normally, sensitivity functions for natural environmental factors which express their direct relationships to the output parameters will not be required during Concept Formulation. While natural environmental factors technically are accountable factors for system behavior, they directly affect the design values achievable by the critical accountable factors. The natural environmental factors cause a critical accountable factor to depart from a desired output value in the form of a shift in its design nominal value, or excessive variation in its output distribution and, therefore, can be considered as belonging to a class of lower-level accountable factors to be analyzed in later phases.

With the sensitivity relationships, a preliminary optimization of each output parameter can be accomplished. This must be tempered with a composite FOM and cost optimization described in a later step. A description of the output distribution

for each output parameter also can be made. With all sensitivity functions linearized, the mean of the output distribution is directly obtainable from the transfer functions. This is the response value corresponding to the critical accountable factors being assigned their selected optimum nominal value. The variance (a measure of variation) can be estimated as the sum of the postulated inherent variances for each accountable factor. An estimate then can be determined for the probability that an output parameter will exceed a limiting value. These are required inputs for an FOM evaluation.

An alternate procedure for determining the response distribution is to use a standard procedure such as Monte Carlo simulation. Such a complex procedure normally should not be attempted unless sufficient design details are available.

Procedure

The procedure for the technical accomplishment of the effectiveness parameter selection step can be summarized by the following general activities:

- Identify those system functions and parameters which are critical to the preliminary FOMs. (For example, assume that the FOM prescribed for a close-support aircraft is the probability that a single aircraft will destroy an assigned target of a specified posture. Ideally, a close-support aircraft would be assigned to destroy as many targets and make as many passes as its weapon delivery capability would allow. Additionally, if an aircraft has a low probability of kill per pass, multiple aircraft may be committed as a normal tactic. For such a system, the primary contributions to effectiveness are supplied by the navigation, target acquisition, and weapon delivery functions. One area where a significant payoff in effectiveness is apparently present is by increasing navigation accuracy. This will (1) enhance the ability to locate the identification point under marginal weather conditions, (2) increase probability of acquiring targets under marginal weather conditions, (3) decrease pilot workload, thus enhancing survivability through reduced pilot errors, and (4) provide greater accuracy of inputs to the bombing computer. One of the critical functions, therefore, is the navigation function with the needed navigation accuracy being its critical performance parameter.)

- Identify quantifiable, critical accountable factors for each critical system performance parameter contributing to the effectiveness parameters of availability, dependability, and capability.

- Establish a criticality matrix for each FOM to provide a visible perspective of the relative contribution to the FOM and each effectiveness parameter of the critical top-level system parameter and its accountable factors

- Assign preliminary rankings of criticality

- Develop the needed set of gross transfer functions to describe mathematically the functional cause-and-effect relationships of the critical accountable factors to their system performance parameters. Examples of transfer functions are listed in Table 3-5.

- Analyze the sensitivity of each selected output performance parameter to a candidate range of achievable values for its critical accountable factors, using simplified simulation or theoretical analysis techniques. Portray the response with a curve and a simple mathematical function

- Identify the response region where the best values for optimum results are included. Linearize the function (or curve) in this region.

- Convert the results of the sensitivity analysis to sensitivity coefficients. Revise composition and rankings of criticality matrix as needed.

Information Flow

The basic data required for the effectiveness parameter selection activity are:

- The results of the performance requirements analysis of Step E3

- The results of the operational requirements analysis of Step E4

- The proposed system maintenance functions, operational test and activation functions, Requirements Allocation Sheets, Trade Studies, and Time Lines from the Develop Gross Functions activity of the systems engineering process as described in AFSCM 375-5

- The initial system design/performance requirements, and their values, from the Determine Design Requirements activity of the systems engineering process as described in AFSCM 375-5

TABLE 3-5 EXAMPLES OF TRANSFER FUNCTIONS

Transfer Function	Accountable Factor
• Basic availability equation (A)	Reaction time Mean time to preventive maintenance Mean time required for repair Mean time to failure
• Basic dependability equation (D)	Operating time Failure rate In-flight repair rate
• Basic survivability equation (D)	Dispersion Hardness Reaction time
• Available flights per month for aircraft systems (A)	Mean turnabout time Fraction of total time in flight Mean time to restore
• Breguet range equation for aircraft systems (C)	Lift and drag coefficients Weight of aircraft at takeoff and at landing Density of atmosphere Specific range of fuel Wing area
• Drag equation for aircraft or missile systems (C)	Maximum frontal area Angle of attack Velocity Density of atmosphere
• Maximum range equation for ballistic missile systems (C)	Earth's radius Earth's surface gravity Burnout velocity
• Point target kill probability equation for missile systems (C)	Radius of effect of ordnance Accuracy of delivery of ordnance
• Thrust equation for booster systems (C)	Nozzle throat area Thrust coefficient Characteristic exhaust velocity Chamber pressure

TABLE 3-5 EXAMPLES OF TRANSFER FUNCTIONS (Continued)

Transfer Function	Accountable Factor
• Equation of motion for booster systems (C)	Velocity of exhaust Direction and magnitude of thrust forces Mass vs. time curve
• Kepler's laws for orbital period and velocity for satellite systems (C)	Maximum and minimum distance of satellite from the center of the earth or other attracting body Mass of attracting body
• Transfer period sensitivity equation for spacecraft systems (C)	Velocity of vehicle and error in velocity Orbital parameters
• Rayleigh scattering law for small objects for radar systems (C)	Wavelength of radar Radius of object
• Range equation for radar systems (C)	System loss factor Transmitted power Cross section of detected object Power gain of the antenna Radar wavelength Signal-to-noise ratio
• Probability of detection equation for radar systems (C)	Threshold voltage Amplitude of signal or noise
• Spiral search acquisition probability equation for radar systems (C)	Distance between curves on spiral One sigma acquisition radius Number of sensors Single pass acquisition probability Dispersion in probable location of target

(A) denotes availability function
(D) denotes dependability function
(C) denotes capability function

- The ROC and RAD requirements and preliminary FOM descriptions
- The theoretical and empirical design equations, physical laws, and probability relationships used to relate the ensemble of broad system inputs to outputs from the initial concept trade-off studies.

The results of the effectiveness parameter selection activity will be used to structure the effectiveness models to be applied for the evaluation and optimization of the candidate system concepts with respect to the FOM measures. Upon completion of the subsequent effectiveness evaluation and optimization analysis, a final adjustment of the criticality matrix may be necessary prior to its inclusion in the CFP/TDP.

Figure 3-6 shows the basic information network of the effectiveness parameter selection activity.

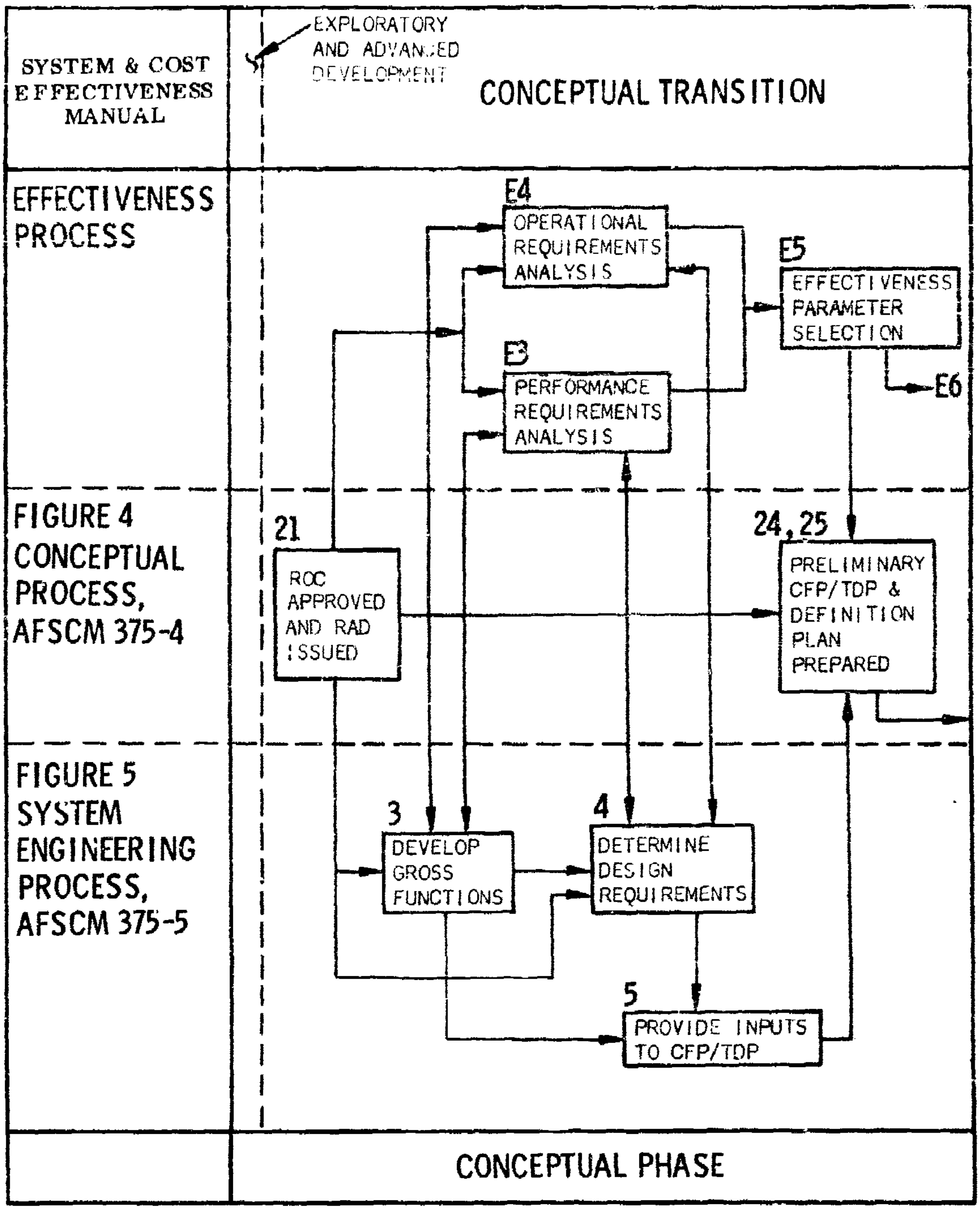


Figure 3-6	Effectiveness Parameter Selection Information Network	Page 3-41

3-7 MODEL STRUCTURING STEP E6

General

Effectiveness models are required to evaluate the capabilities of the candidate design concepts with respect to their current and projected performance potentials and economy. These models are usually in the form of mathematical equations suitable for direct or computer simulation analysis. A system effectiveness model is used to measure technical performance as a function of either the effectiveness parameters of availability, dependability, and capability, or as a direct function of the critical system parameters composited by the effectiveness parameters. A cost model is used to measure the cost performance of the candidate designs based on the resource parameters. A cost effectiveness model provides a measure of the relative merits of the designs with respect to the efficient balance of technical performance and cost.

System effectiveness models are to be developed for each defined preliminary FOM. These models are to be adaptive for the evaluation of multi-threats, alternate modes of operations, critical accountable factors, and similar influences which may measurably affect the FOM potential of a system. System effectiveness models normally will consist of several submodels, with each submodel based on models at still lower levels. Because of the interactions among the submodels, model integration will be necessary. Where design details permit during Concept Formulation, first-level system submodels are to be formulated in addition to top-level models.

System and cost effectiveness submodels which may be structured for the evaluation of the spectrum of technical performance parameters of a system include models for:

- Each effectiveness parameter
- Each subsystem FOM, reflecting the contributions to the system FOMs of the restrictive mission objectives associated with a subsystem's capabilities and role in each mission assignment (normally not required during Concept Formulation).
- Each critical accountable factor (normally not required during Concept Formulation).

The structuring of effectiveness models during Concept Formulation is a four-step process involving:

- Defining analysis assumptions
- Formulation of effectiveness parameter models
- Integration into overall FOM models
- Integration of FOM models into overall cost effectiveness models

Defining Analysis Assumptions

Prior to the formulation of an effectiveness analysis model, a listing of assumptions, including their explicit rationale and justification, is required. This listing should include the major assumptions influencing the validity, credibility, realism, and confidence to be attached to the model and model outputs. Assumptions to be listed and justified during Concept Formulation, in order of decreasing criticality, include those addressing technical uncertainties associated with:

(1) FOM definition

(2) Mission scenarios and strategic content, mission performance and operational requirements, and mission conditions (most probable and worst situation)

(3) Transfer functions, procedures used to generate these functions, system performance parameters, and accountable factors, including values achievable.

(4) Source data representativeness

(5) Mathematical approximations used to simplify analysis, form of probability distributions for the ensemble of system input-output functions, linearity approximations, and dependencies or interactions of functions.

To the extent possible, unifying sets of assumptions should be preestablished for (1) and (2) by the AF technical activities and reflected in the RAD. These assumptions should cover any basic uncertainties about the mission content and the requirements against which system terminal performance is to be measured.

While the evaluation of FOMs and their effectiveness parameters is sensitive to the nature and criticality of assumptions, it is also sensitive to the validity of the rationale and justifications underlying the assumptions. In turn, the validity of the rationale and justiciations used for the needed assumptions is dependent upon the quality of the supporting data base to be used. In an order of decreasing quality, the following data bases are normally usable to support assumptions during Concept Formulation:

(1) Proven concepts and/or facts substantiated by in-depth studies (e.g., war game analysis, in-depth intelligence reports, minor extensions of current state-of-the-art, etc.)

(2) Repeatable experimental results verifiable by theory

(3) Theoretical or scientific hypotheses not verified experimentally nor empirically.

(4) Major extrapolations from similar or related systems

(5) Engineering guesses

The composite influence of the nature and criticality of assumptions made, and of the validity of the justifications for these assumptions, is an error in the calculated value for each FOM. The largest error will be associated with the use of many highly critical assumptions and insufficient justifications. A determination of the magnitude of the composite error can be made based on worst case analysis and reflected in the calculated FOM in terms of an interval (e.g., plus and minus three standard deviations) in which the FOM value is expected to be included. Where data permit, this interval is extendable to include statistical uncertainties (risks).

Formulation of Effectiveness Parameter Models

Models are to be formulated for each effectiveness parameter of availability, dependability, and capability to integrate their respective set of system performance parameters. In the formulation of these models, many decisions must be made. These decisions basically address the extent to which the presence of certain operational conditions will significantly influence the effectiveness parameters and the FOMs, such as different system states, multiple threats, and multiple missions.

Mission accomplishment is directly affected by the different significant states that the system may occupy during its mission assignments. These states refer to the different functional conditions of the system at the beginning of the mission, during the mission, and upon completion of the mission. For a complex system, there theoretically may be a continuous spectrum of system states. One extreme of the spectrum is represented by the state associated with the system completely functioning properly without error, the fully operable state (mission not aborted). The opposite extreme is the state associated with the system completely inoperable (mission aborted). A significant intermediate state would be the fail-operable condition of the system (major elements of the system failed, but not requiring mission abort). From a practical implementation viewpoint, it is necessary to group states to reduce their total number to a manageable size suitable for rapid effectiveness evaluations. Thus, during Concept Formulation, it is expected that system functional analyses will only be of sufficient detail to allow for a simplified two-state analysis (operable and inoperable states).

In addition to selecting and defining the significantly different states to be addressed by each effectiveness parameter model, specific technical details necessary for overall model integration and evaluation of a system's FOMs are to be developed. These are:

- A graphical representation of the system progression from state to state during the time periods of the missions. Figure 3-7 illustrates a typical system effectiveness state flow graph for a simplified two-state analysis. For this representation, the states are considered to be applicable over the entire mission profile, independent of time intervals for which the mission may be partitionable.
- The determination of probabilities for each of the significant mission states. For a system which is considered to occupy only one of the two states of operable and inoperable at any time prior to, during, or at the end of the mission, estimates are required of the probable occurrence of each state.

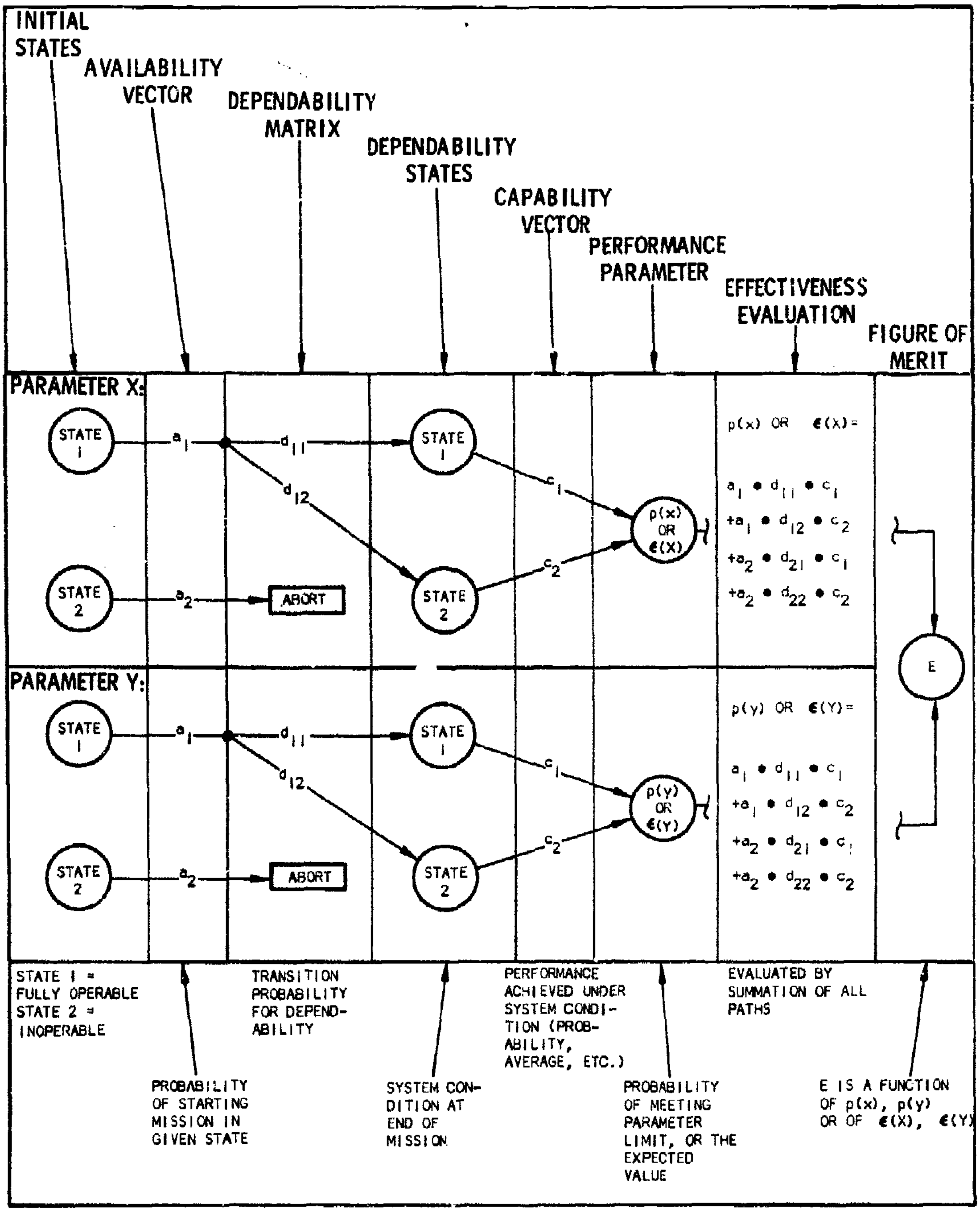


Figure		Page
3-7	System Effectiveness Two-State Flow Graph	3-46

Mission accomplishment is further influenced by the type and magnitude of natural environments and hostile enemy threats. As previously indicated in the Effectiveness Parameter Selection Step, natural environmental stresses normally can be considered and evaluated as influences to critical accountable factors. Their range of values are reasonably and accurately predictable. On a comparative basis, the type and magnitude of hostile enemy threats, previously identified in the Mission Analysis Step, will have the more serious effect on performance. When considering the influences of different types and magnitudes of enemy threats, an analysis based on the most probable level of threat can result in the selection of a system concept which may be extremely ineffective in the presence of a different and worse level of threat. The selection of a system which can respond to the worst level of threat, although it may have a low probability of occurrence, also may have unsatisfactory consequences because of the conservatism of this approach and its usual high attendant cost. A technical decision will be required as to the manner in which multiple threat influences are to be reflected in the analytical results. A practical procedure to follow is to establish distinctly different groupings of threats by severity level, on the order of approximately four levels, with probabilities assigned for the expected occurrence of each level. Each effectiveness parameter should then be evaluated against each defined level. As a minimum, the effect of the most probable and the most severe levels should be assessed to provide a common comparative basis for concept selection decisions.

Multiple missions impose additional conditions on the formulation of the analytical models for the effectiveness parameters. Different mathematical expressions for the models will be required for each mission in the majority of cases. Additionally, model outputs must be in the same measurement unit if FOMs are to be combined. Multiple modes of operation also will require a separate modeling consideration.

Integration Into Overall FOM Models

In addition to defining and formulating the analytical models for the individual evaluation of the effectiveness parameters, a composite system effectiveness model must be developed for each of the defined preliminary FOMs. These composite models will

be the analytical mechanisms for the quantitative determination of a system's technical FOM potentials. Also, the development of an overall system cost model will be required, as well as a cost effectiveness model to integrate the system effectiveness and cost models.

The structuring of each system effectiveness model is a two-step process. Initially, the submodels for the critical functional, specialty, and operational system parameters are composited into their respective effectiveness parameter sets of availability, dependability, and capability. A typical procedure would be to apply a product rule, since the individual system parameters normally are independent, or can be subgrouped into more inclusive independent parameters. Following this step, the effectiveness parameter sets then can be integrated into overall FOM models. Examples of simplified overall system effectiveness models useful for application during Concept Formulation are presented in Table 3-6.

Integration Into Overall Cost Effectiveness Models

The integration of the separate system effectiveness models and cost models into a single cost effectiveness model for each set of mission objectives, and the analytical results obtainable from the use of the integrated models, provide a comparative basis for system concept selection. Additionally, by comparing the cost effectiveness of the preferred concept to that of competing systems on a DOD-wide basis, a determination can be made of the preferred system's performance-cost stance. A favorable comparative result is one of the prerequisites for obtaining conditional approval to proceed with the Contract Definition Phase and subsequent engineering development.

Examples of cost effectiveness models useful for Concept Formulation applications are listed in Table 3-7. The structuring of the cost effectiveness model involves defining the cost effectiveness selection criteria (a single criterion for single mission systems) which is to be used as a common measure for all competing system concepts. Normally, the criteria are to be stated in units of dollar cost per unit of mission task performed, or the equivalent inverse form. Examples of cost effectiveness measures

TABLE 3-6 EXAMPLES OF SIMPLIFIED SYSTEM EFFECTIVENESS MODELS FOR CONCEPT FORMULATION APPLICATIONS

Type of Mission	Characteristic	Model
SIMPLE DISCRETE AND CONTINUOUS MISSIONS		
o Discrete (with respect to mission time)		
Non-recurring	Mission is short in duration, and system expended after one mission assignment	FOM evaluated as simple ADC* product, or as an average or minimum capability.
Recurring	System is reusable and is operationally employed on many assignments to accomplish the same set of mission objectives	FOM is a measure of average or minimum capability
• Continuous (with respect to mission time)	System is operationally employed over an extended period of time	FOM is integral over time of ADC product, with D and C potentially changing with time. Where a worst case analysis is appropriate, the FOM is a minimum value of the ADC product
COMPLEX DISCRETE AND CONTINUOUS MISSIONS		
• Multiple levels of threats	System is operationally employed in the face of all threat levels	Effectiveness E is min $\{E_i\}$ or most probable, where E_i is FOM for i-th threat level. Also, E may be expressed as $\Sigma p_i E_i$, where p_i is the probability of i-th threat level occurring
• Multiple missions for discrete and continuous missions	System is operationally employed for a variety of missions. A composite FOM for all missions can be realistically defined	E is min $\{E_j\}$ or most probable, where E_j is FOM for j-th set of mission objectives. Also, E may be expressed as $\Sigma p_j E_j$, where p_j is probability of j-th mission occurring
• Multiple missions and threats	System is operationally employed in the face of all threat levels and for a variety of missions. A composite FOM for all missions can be realistically defined	E is min $\{E_{ij}\}$ or most probable. Also, E may be expressed as $\sum_j \sum_i p_{ij} E_{ij}$

* A = Availability D = Dependability C = Capability

TABLE 3-7 EXAMPLES OF COST EFFECTIVENESS MODELS

- System effectiveness (E) for a fixed cost (C)
- Cost (C) for a fixed level of system effectiveness (E)
- System effectiveness (E) per cost (C), or cost (C) per system effectiveness (E) - (Ratio Model)
- Net value* (V) received for cost (C) expended - (Net Value Received Model). Can be expressed as:

  Net value received = VE - C
  = gross value received minus cost
  = value per increment of effectiveness times planned level of effectiveness minus cost

- Net rate of return per unit of cost - (Rate of Return Model). Can be expressed as:

  $$\text{Net rate of return} = \frac{VE - C}{C}$$
  = Net value received per cost

- Gross value received, averaged over entire life of system, per cost (C) - (Long Term Ratio Model). Can be expressed as:

  $$\frac{1}{C(t_o - t_d)} \int_{t_d}^{t_o} V(t)\,E(t)\,dt$$ where $(t_o - t_d)$ is remaining useful life

*Value (V) is assignable to a fixed increment of system effectiveness (e.g., X dollars per .05 increment of E), and is expressed in units of cost (C) per effectiveness (E).

for various classes of Air Force systems are listed in Table 3-8. This table is essentially a derivative of Table 3-1, Figure of Merit Examples, previously described in paragraph 3-3. A criterion for system selection which is responsive to mission objectives is typically based on one of the following rules:

(1) The maximum system effectiveness for a fixed cost

(2) The maximum system effectiveness per unit of cost, or its inverse. Rules (1) and (2) will have general applicability during the Concept Formulation Phase.

(3) The minimum cost for a level of system effectiveness.

Formulation of Cost Models

Tasks and factors relevant to the construction of a cost model for each set of mission objectives to provide a quantitative analysis of the total system costs involve the following:

- Identification of cost resources and constraints (schedule demands, size of commodities such as operating skills, critical material, technology, and dollars)
- Identification and synthesis of cost alternatives, including the affected critical accountable factors and system performance parameters
- Development of cost relationships and the cost models.

Cost measures should be capable of accommodating the assessment of major types of resource expenditures on a common basis, such as dollar cost. Toward this end, the development of cost models will be needed to evaluate separately the major components of total cost. These are the components of development costs, acquisition costs, and operational costs (including logistics support elements such as maintenance). Additionally, separate evaluation of costs will be required for alternate development schedule time spans, if appropriate, and if the time span alternatives are sufficiently different so as to affect the efficient utilization of resources.

TABLE 3-8 EXAMPLES OF COST EFFECTIVENESS MEASURES

System Class	Cost Effectiveness Measure*
• Interceptor	(a) Expected number of enemy aircraft destroyed per unit of cost (b) Expected number of hours of training per unit of cost
• Strategic Bomber	(a) Expected number of point targets destroyed per unit of cost (b) Expected number of hours of training per unit of cost
• Tactical Aircraft	(a) Expected number of sorties per unit of cost (b) Expected number of successful close air supports per unit of cost (c) Expected number of successful tactical bombing missions per unit of cost (d) Expected number of successful reconnaissance missions per unit of cost (e) Expected number of successful air escort missions per unit of cost
• Transport	(a) Expected number of consecutive deliveries of specified cargo to its destination within (x) hours per unit of cost of delivery (b) Minimum cost-time product required to deliver a specified cargo (c) Expected number of ton-miles of general cargo transported per unit of cost (d) Expected number of consecutive take-offs and landings in (x) distance with a specified gross weight per unit of cost per trip
• Space Launch Vehicle	(a) Expected number of pounds of payload placed in a specified orbit per unit of cost

*Cost normally will be in terms of dollars.

TABLE 3-8 EXAMPLES OF COST EFFECTIVENESS MEASURES (Continued)

System Class	Cost Effectiveness Measure*
• Communications Satellite	(a) Expected number of consecutive successful attempts to transmit a high priority message within (x) seconds per unit of cost
	(b) Expected number of bits of low priority messages transmitted per unit of cost
	(c) Expected number of channel-years operating at a minimum specified effective radiated power per unit of cost
• Intercontinental Ballistic Missile	(a) Minimum cost of destroying a prescribed target of (x) hardness with a prescribed probability
	(b) Expected number of targets of (x) hardness destroyed per unit of cost
	(c) Expected dollar value, strategic value, or percent of damage to enemy property per unit of cost
• Air Interceptor Missile	(a) Expected number of enemy aircraft destroyed per unit of cost
• Air-to-Ground Missile	(a) Expected number of targets of (x) hardness destroyed per unit of cost
	(b) Expected level of damage to (m) hardened targets per unit of cost
	(c) Minimum cost required to destroy (n) or more of (m) specified targets
• Command and Control	(a) Expected number of stored bits of information retrieved within a specified time and probability per unit of cost
	(b) Expected number of intercepts or track-hours of friendly aircraft per unit of cost given a specified level of enemy activity
	(c) Expected number of intercepts or track-hours of enemy aircraft per unit of cost
• Warning and Detection	(a) Minimum cost of detecting and tracking an object with a specified probability
	(b) Expected number of track-hours with a specified accuracy of track per unit of cost

*Cost normally will be in terms of dollars.

In formulating the cost models, special emphasis should be given to insure that the models have the capability to accommodate the following:

- Inclusive identification of cost by categories, including the nature of historical data to be used as a basis for projecting cost. A guideline for a typical breakdown of development costs, acquisition costs, and operational costs by categories is presented in Table 3-9.
- Estimation of total and per year cost by broad aggregations. Thus, it is expected that cost estimates below the categories listed in Table 3-9 will be required only in the special case where sufficient design or operational details are available
- Estimation of total cost on a basis suitable for use in guiding Air Force system selection decisions.
- Cost sensitivity and variance analysis to provide a perspective of the precision of the cost estimates and to assess the influences of cost uncertainties. A procedure based on a cost variance concept or a PERT-cost analysis of least possible, expected, and maximum possible cost can be applied to extrapolations of historical data from similar or related systems.

Procedure

The procedure for the technical accomplishment of the model structuring step can be summarized by the following general activities:

- List major assumptions used, including their explicit rationale and justification
- Select and define the significant states which are to be incorporated into each effectiveness parameter model. For simplicity, use a two-stage analysis
- Represent graphically the progression of the system from state to state for the time periods of the mission
- Determine probabilities for each of the defined states which are appropriate at the beginning and during the mission

TABLE 3-9 EXAMPLES OF COST CATEGORIES* FOR COST EFFECTIVENESS ANALYSIS

Development Costs (RDT & E)

- CFP and CDP studies
- Development of each stage and subsystem of system
- AGE development
- Training equipment development
- Test program and test articles, including spares, AGE, and operational test personnel training
- Configuration management
- Technical data

Acquisition Costs

- Purchase and rework of major manufacturing facilities
- Purchase of hard tooling
- Purchase of new basic facilities
- Transportation and delivery of systems
- Purchase of information network facilities
- Purchase of depots and logistics support bases
- Production of ancillary equipment
- Purchase of initial spares
- Training equipment
- Technical data
- Modifications of systems
- Stage and subsystem production (including AGE & OGE)

Operational Costs

- Materials for operations and turnaround
- Operating personnel
- Training exercises and aids
- Spares replenishment
- Depot and base operations and maintenance
- Equipment maintenance

*For some applications, it may be necessary to further divide the cost categories into recurring and non-recurring costs, direct and indirect costs, or any combination thereof. Also, depending on the depth of Concept Formulation studies and of the technological advances involved, a combining of the listed cost categories may be more appropriate for the cost analyses.

- Define and formulate models for the availability, dependability, and capability effectiveness parameters to be used in the evaluation of each preliminary FOM. Each model normally will be a composite of submodels for its appropriate critical system performance parameters previously identified, defined, and functionally related to critical accountable factors in Step E5.
- Group threats into distinct levels.
- Integrate the availability, dependability, and capability parameter sets into an overall system effectiveness model which can be used to calculate an FOM. Where more than one preliminary FOM is applicable, a separate overall model will be required to evaluate each FOM
- Determine the feasibility of combining FOMs. If technical meaning can be attached to a combined measure, then establish a method for combining multiple FOMs
- Define and structure cost effectiveness model. Define system concept selection criteria (criterion)
- Define cost measure. Identify significant cost resources and constraints
- Develop cost relationships. Also formulate a cost model for each FOM with the capacity to accommodate estimates of total and per year costs by broad aggregations and cost sensitivity and variance analysis

Information Flow

The basic data required for the model structuring activity are:

- The results of the mission analysis activity of Step E1 for the identification of the applicable mission states and the establishment of the analysis framework for multiple threats
- The defined FOMs from the specifying of preliminary FOM activity of Step E2
- The results of the effectiveness parameter selection activity of Step E5 which established the critical system parameters to be included in the availability, dependability, and capability models

- The ROC, RAD, and program task statements for determining the technical performance and cost constraints, and for a selection criterion which may be included
- Cost data from cost analyses.

The effectiveness parameter models and overall system FOM models formulated from the model structuring activity will be used for the system and cost effectiveness analysis to determine the system performance and cost potentials with respect to each defined FOM, and to a combined, single FOM, if appropriate. Figure 3-8 shows the basic information network for this activity.

3-8 SYSTEM AND COST EFFECTIVENESS ANALYSIS $\boxed{\text{STEP E7}}$

General

The principal use of the models for system effectiveness, cost, and cost effectiveness developed in the previous step of the effectiveness process is to provide an estimate of current effectiveness and a prediction of the effectiveness growth potential expected to be present in five years. These estimates are directly usable to:

- Provide a timely and objective management decision criterion for the selection of the preferred system
- Highlight technical and cost weaknesses of the system, or potential problem areas requiring resolution during later phases
- Justify proceeding with the Contract Definition Phase and subsequent engineering development
- Provide the initial traceability of critical system performance parameters to preliminary design requirements.

A system and cost effectiveness analysis is an iterative, trade-off process involving the use of optimization techniques to arrive at a design concept with the best balance of technical performance and total life cycle costs to meet mission objectives. Simple optimization techniques which have general and practical applicability during Concept Formulation include:

- Simple maximization method. This technique is applicable when the accountable factors must be restricted to a limited range of candidate values. The FOM is evaluated for each value in the range of alternate values for each accountable factor

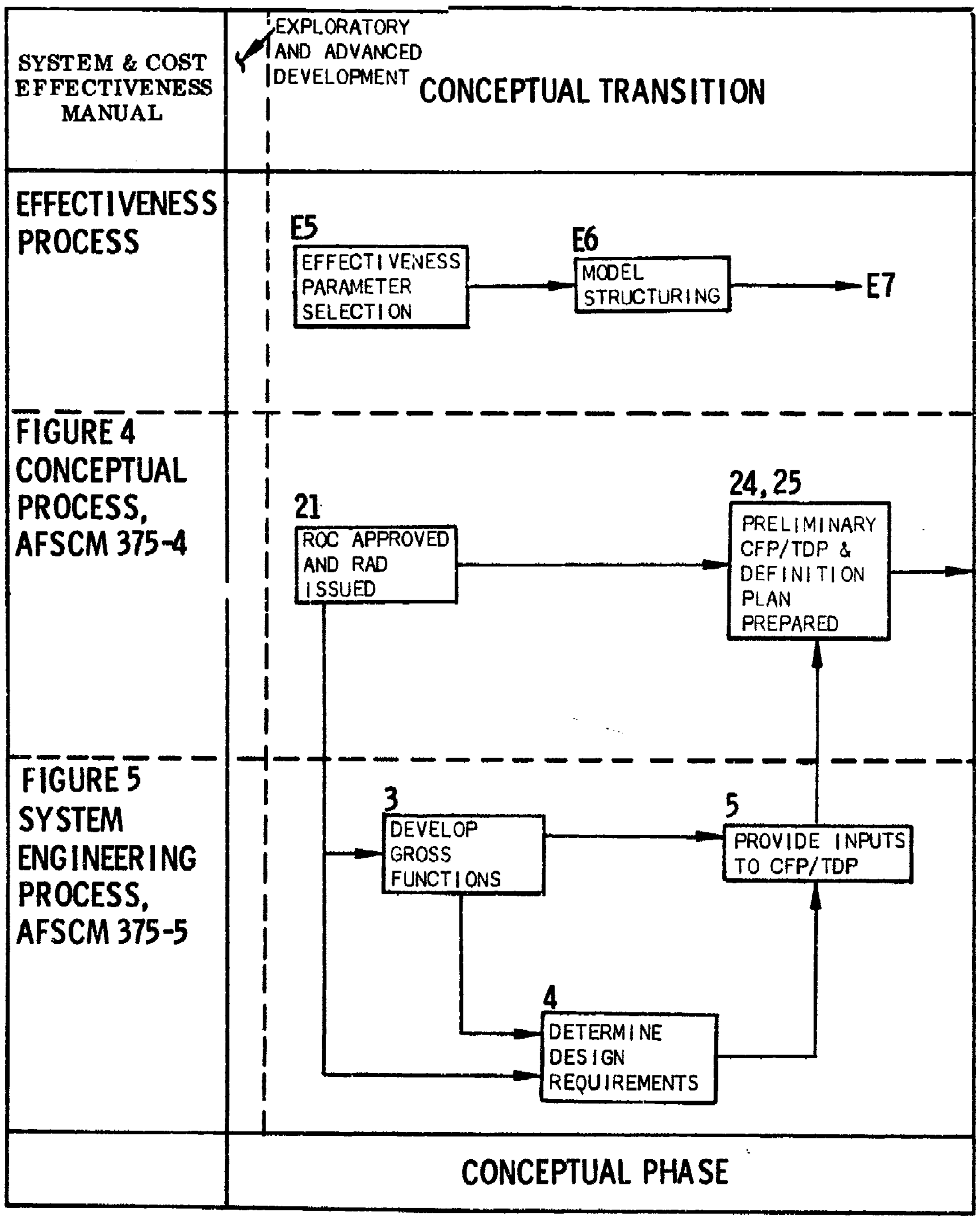


Figure 3-8	Model Structuring Information Network	Page 3-58

- Method of steepest ascent. This technique is applicable when the FOM depends in a linear or otherwise simple analytical form on its accountable factors. Alternate values for the accountable factors are chosen so as to increase the FOM in steps which are as large as possible.
- Graphical method. This technique is applicable if the transfer functions and constraints are based on empirical data or curves.

Evaluation of FOMs and Cost Effectiveness

The evaluation of the current effectiveness potential of each system concept involves computing the FOMs based on calculated values for the availability, dependability, and capability parameters. A preliminary design is chosen by repetitive analyses. Each of the performance and cost alternatives is analyzed, and the results are compared with a previous choice. This process is inherently difficult since it involves choosing an optimum value for many system parameters, each of which is affected by numerous accountable factors with different inputs. The synthesis method for speeding this trial and error selection process with an orderly and systematic solution, in addition to providing considerable insight into the design problem, has been described in Step E5. In using this method, system developers will have visibility of how the input, output, and system functional characteristics are connected, what sensitivities are best, and the limitations of the system performance capabilities.

While the system developers will have the freedom to adjust the system parameters and accountable factors to their best values and for best cost, there remains the problem of determining which combination will provide the optimum system and cost effectiveness. A practical method for providing this perspective is to develop sensitivity functions which will directly relate incremental changes in critical accountable factors to a corresponding magnitude and direction of change in the FOMs. This form of sensitivity functions may be generated directly. Alternately, it may be developed by combining the sensitivity functions previously prepared, which related the accountable factors to effectiveness parameters, with a sensitivity function relating the set of effectiveness parameters to each FOM. The general procedure for arriving at this combined sensitivity function for an FOM is described in Appendix C. Based upon such relationships, the preliminary criticality matrix

initially formulated in Step E5 can be updated, and the ranking and the index of relative criticality of accountable factors to the effectiveness parameters and the FOM revised.

With the cost effectiveness optimization of a system concept and a determination of its current FOM potential, an optimum system effectiveness value will be obtained. Due to the statistical distribution properties of the accountable factors, the FOM is a distribution of values. If each accountable factor influences its FOM independent of another accountable factor, then an estimate of the variance for the FOM can be obtained simply. This variance will be the sum of the variances for the individual accountable factors. In addition to the best estimate, a lower confidence estimate can be prepared to account for inherent statistical risks. Also, an estimate of the error range to be associated with the uncertainties of critical model assumptions can be calculated.

Analyses Required

The goal of system and cost effectiveness evaluations during Concept Formulation is to provide specific outputs usable for management decisions. Interim analysis results provide Air Force and contractor management with the necessary visibility for creating the best system concept, given the technical and other resources at their disposal. Correspondingly, the final analysis results provide criteria for Air Force management decisions on the preferred system concept(s) to select. Additionally, they contribute to the necessary technical and cost justifications for proceeding with subsequent phases of the program.

Standardization of a desired set of analytical outputs is necessary to insure an objectively candid and compatible Air Force evaluation of the candidate systems. As a minimum, therefore, the system and cost effectiveness analysis activity is to be directed at providing current and predicted estimates of the performance and cost characteristics of the candidate system concepts. Measures to be evaluated during Concept Formulation are:

- FOMs
- Cost effectiveness
- Availability

- Dependability
- Capability
- Each critical system parameter constituting the availability, dependability, and capability parameters

To the extent possible, both a mean estimate and a lower confidence estimate is to be provided for these measures, along with the expected error range for both types of estimates. The principal uses in the decision process of these estimates resulting from the effectiveness analyses are listed in Table 3-10. Also listed are examples of measurement units which will require designation prior to any evaluation of system and cost effectiveness for concept comparison purposes.

A decision is required as to how to optimize for multiple missions for which different preliminary FOMs have been defined. Usually one of the following rules can be applied as a compromise:

- Optimize to the most significant FOM (difficult, primary, etc.) subject to meeting minimum performance on the balance of the FOMs.
- Optimize to improve the lowest FOM value.
- Optimize to an average or weighted average FOM, where such a measure has an operational physical parallel.

Procedure

The procedure for the technical accomplishment of the system and cost effectiveness analysis step can be summarized by the following general activities:

- Identify the vital trade-off factors available within constraints, to include alternatives for critical system parameters, critical accountable factors, and cost elements.
- Determine values of accountable factor which will maximize the effectiveness parameters, using the sensitivity functions developed in Step E5. An accountable factor which influences more than one parameter will require a composite optimization at the overall FOM level.

TABLE 3-10 MINIMUM ANALYSES REQUIRED AND PRINCIPAL USES

Analysis	Unit of Measure	Principal Use
• System Effectiveness (FOMs)	Probability or expected value	Measure of overall technical performance and response to mission objectives. System selection criterion and justification.
• Cost Effectiveness	System effectiveness per cost Dollar value per cost Dollar value System effectiveness per unit time per cost	Measure of overall technical and cost performance and response to mission objectives. System selection criterion and justification.
• Availability	Probability or expected value as a function of total turn-around time In-commission ready rate Utilization rate	Measure of system condition at start of mission. Provide intelligence on potential operational problem areas and traceability of preliminary design requirements.
• Dependability	Probability or expected value as a function of mission time, failure rate, in-mission repair rate, alternate modes of operation, reaction time, and dispersal distance	Measure of system condition at one or more points during mission, given the system condition(s) at the start of the mission. Provide intelligence on potential reliability and survivability problem areas and traceability of preliminary design requirements.
• Capability	Probability or expected value	Measure of system ability to achieve mission objectives. Provides intelligence on potential general limitations of system's performance capabilities, problem areas, and traceability of preliminary design requirements.
• Critical System Parameters	Probability or expected value	Individual measure of each critical performance capability or characteristic of system. Provides intelligence on potential design problem areas, safety margins, and traceability of preliminary design requirements.

- Develop a sensitivity function to relate incremental changes in the values of accountable factors to changes in an FOM.
- Calculate the FOMs based on the accountable factor values and using the FOM models developed in Step E6.
- Calculate the cost associated with the selected alternatives.
- Optimize the FOM and cost interactions, and calculate the cost effectiveness measure, using the model defined and developed in Step E6.
- Calculate a lower confidence estimate for each FOM based upon statistical distribution principles.
- Update the preliminary criticality matrix prepared in Step E5.
- Compute a confidence estimate for the cost effectiveness measure, using statistical distribution principles and a cost variance analysis technique.
- Compute an error range for the FOM and cost effectiveness estimates to account for assumption errors.
- Tabulate for each mission, and for the most probable and worst threat levels, the current and predicted (for a period of time five years hence) values for the FOM and cost effectiveness measures, the availability, dependability, and capability parameters, and the critical system parameters.
- Compare candidate system concepts with respect to all these classes of estimates for intelligence as to the concept to select.

Information Flow

The basic data required for the system and cost effectiveness analysis activity are:

- The alternate functions and their associated performance parameters and accountable factors, and the candidate range of values for the critical accountable factors. These were identified in Step E6 with significant inputs from the Develop Gross Functions and Determine Design Requirements activities of the systems engineering process defined in AFSCM 375-5.

- The models, model assumptions, technical performance and cost constraints, and optimization criteria from the model structuring activity of Step E6.
- The cost data for the various alternatives.
- The sensitivity functions and criticality matrices from the effectiveness parameter selection activity of Step E5.

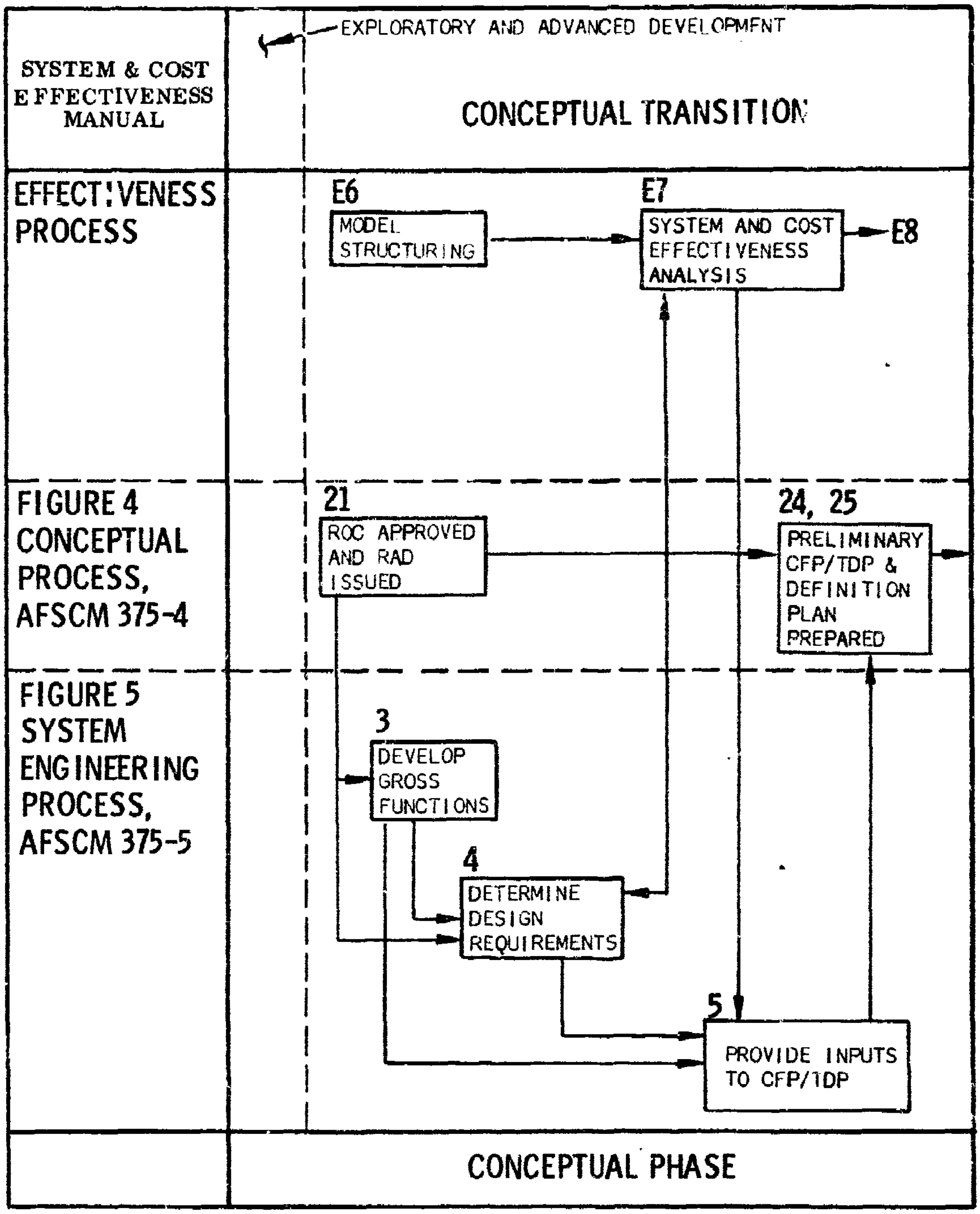
The principal uses of the analysis results are as previously delineated in Table 3-10. Additionally, the analysis results are to be incorporated into a report which summarizes the major outputs of the system and cost effectiveness management implementation process developed during Concept Formulation. The basic information network for the system and cost effectiveness analysis step is shown in Figure 3-9.

3-9 REPORT STEP E8

General

A report is to be prepared and submitted to the Air Force technical activity summarizing the system and cost effectiveness formulation and evaluation results for the Concept Formulation Phase. The technical data to be included in this report will serve many vital needs of the system planners at HQ USAF, HQ AFSC, and the SPO cadre. Of dominant relevance are the following anticipated uses of the data:

- To provide the justification for a new system, and to demonstrate that the six prerequisites required for conditional approval to proceed with engineering development have been met. These prerequisites are described in AFR 80-20 and are listed in paragraph 3-1 of this manual.
- To provide a decision criteria for Air Force selection of the most promising candidate system concept(s) to meet current and contingent mission objectives, including strike, retaliatory, and defense capabilities.
- To have available realistic data for updating and refining the RAD, and for establishing the program baseline requirements as part of the planning process for entering the Contract Definition Phase.


SYSTEM & COST EFFECTIVENESS MANUAL
EXPLORATORY AND ADVANCED DEVELOPMENT
CONCEPTUAL TRANSITION
EFFECTIVENESS PROCESS
E6
MODEL STRUCTURING
E7
SYSTEM AND COST EFFECTIVENESS ANALYSIS
E8
FIGURE 4 CONCEPTUAL PROCESS, AFSCM 375-4
21
ROC APPROVED AND RAD ISSUED
24, 25
PRELIMINARY CFP/TDP & DEFINITION PLAN PREPARED
FIGURE 5 SYSTEM ENGINEERING PROCESS, AFSCM 375-5
3
DEVELOP GROSS FUNCTIONS
4
DETERMINE DESIGN REQUIREMENTS
5
PROVIDE INPUTS TO CFP/TDP
CONCEPTUAL PHASE

- To have valid inputs of system performance and cost characteristics for inclusion into the CFP/TDP and the Preliminary Definition Plan to be prepared at the conclusion of Concept Formulation.
- To provide the necessary background and continuity for the related technical activities of the Contract Definition and Acquisition Phases on the traceability of preliminary design requirements and the areas of system and cost effectiveness criteria formulation and evaluation requiring expansion and refinement.
- To focus the inherently critical design and operational problems and limitations requiring further definition, detail analysis, and resolution in later phases. These include those areas of high technical risk, high cost, and insufficient prior analysis.

The system and cost effectiveness report is to include the following technical data:

- An explicit definition and description of the preliminary FOMs, to include mission conditions which apply.
- An explicit definition of the cost effectiveness measure.
- Analysis results giving current and predicted estimates of FOMs, cost effectiveness measures, effectiveness parameters of availability, dependability, and capability, and each critical system parameter constituting the effectiveness parameter sets (e.g., reliability, maintainability, accuracy, etc.). Estimates are to be tabulated by separate FOMs, cost effectiveness measures, and threat levels, as applicable. The precision of the estimates is to be furnished.
- Mission analysis results, including:
  (1) A general description of the intended purposes and functions of the system
  (2) Summaries, descriptions, and analyses of enemy threats, enemy countermeasures, and system neutralizing capabilities
  (3) Interactions of mission requirements with existing systems or systems contemplated to be in use within the same time frame
- System performance requirements profile, including parameters and values

- System operational requirements analyses relating to:
  - (1) Operational requirements profile, including parameters and values
  - (2) Maintenance concept under hostile conditions, such as capabilities for repair of battle damage and for over-ride and temporary correction of malfunctions under hostile conditions
  - (3) Logistics support concept, including maintenance policy and transportability
  - (4) Concept of practice exercises for maintaining system readiness state
- Current and projected technical and cost deficiencies influencing effectiveness
- Criticality matrix, to include relative rankings of system parameters and accountable factors
- Models and submodels used in the evaluation of FOMs, cost effectiveness measures, and effectiveness parameters, including descriptions and listings of:
  - (1) Major assumptions and their criticality
  - (2) Transfer functions used in the evaluation of the critical system parameters
  - (3) System states and probabilities assigned
  - (4) Threat level
  - (5) Major performance and cost alternatives considered
- Sensitivity functions (or curves) relating the critical accountable factors to FOMs or to the effectiveness parameters
- Data sources used in the analyses
- Cost data and cost basis used for the evaluation of cost effectiveness.

Information Flow

All of the major criteria formulation and evaluation activities of the effectiveness process, Steps E1 - E7, will provide inputs to the report, with reciprocating contributions from the systems engineering management activities of Develop Gross Functions and Determine Design Requirements as defined in AFSCM 375-5. The technical data incorporated in the report are directly usable for updating the RAD and for the preparation of the Preliminary CFP/TDP and Definition Plan documents. These documents are an integral part of the program requirements baseline needed to commence Contract Definition. The basic information network for the report activity of the effectiveness process is shown in Figure 3-10.

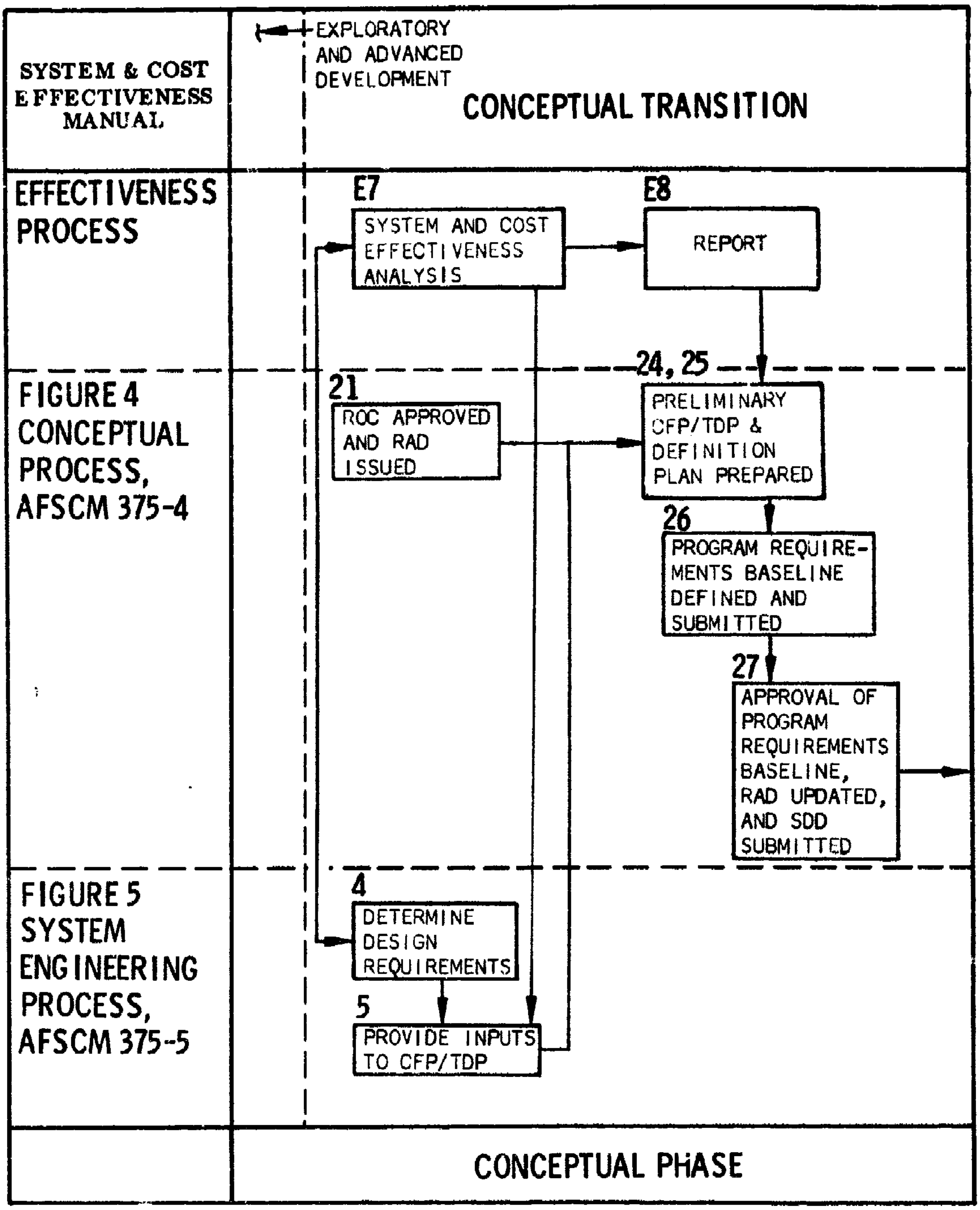


Figure 3-10	Report Information Network	Page 3-69

Chapter 4

SYSTEM AND COST EFFECTIVENESS IMPLEMENTATION FOR CONTRACT DEFINITION PHASE

Summary

The major effectiveness formulation and evaluation activities to be accomplished during the Contract Definition Phase are (1) effectiveness analysis refinement, (2) apportionment analysis, (3) effectiveness progress monitoring and demonstration planning, and (4) report of analytical results. The effectiveness analysis refinement activity is addressed to the necessary improvement and expansion of the technical analysis activities initiated on a gross basis during Concept Formulation for the system being defined in detail. The apportionment analysis activity is directed at the establishment of design criteria which are technically traceable and critical to system effectiveness for inclusion in system and detail specifications. This is accomplished through the optimum allocation of top-level effectiveness-related measures and parameter values to first-level measures and contributing accountable factors. The activity of effectiveness progress monitoring and demonstration planning focuses on the definition of a dynamic monitoring and evaluation program and a demonstration program. These programs collectively will provide a continuing visibility of effectiveness progress so that timely management decisions can be made to insure achievement of an optimum balance of performance, cost, and schedule. The report activity provides the SPO with a compendium of the analytical results and decisions influencing effectiveness which are needed to prepare the baseline documents for the Acquisition decision. The basic manual format used to describe the effectiveness process during Concept Formulation is continued for this phase. The general descriptions of procedures and methods which can be applied, implementation guidelines, and the information flow are delineated on a step-by-step basis. The interactions of the effectiveness activities with the system program management procedures of AFSCM 375-4 on a composited basis also are detailed.

4-1 GENERAL

The Contract Definition Phase is a sequential action process on a time basis, as was characteristic of the Conceptual Phase. The purpose of the Definition Phase is to define as early as possible the cost, schedule, and system elements required to satisfy the approved CFP/TDP, RAD, and other program directives and baseline requirements issued by HQ USAF to direct this phase of the system project. The Definition Phase is intended to achieve specific objectives. These are:

(a) Effective use of defense resources.

(b) Preparation of the System Performance/Design Requirements General Specification (the "System Specification").

(c) Preparation of detailed program management plans.

(d) Determination of realistic cost and schedule estimates. The schedules and cost estimates will reflect requirements for production engineering, facilities, transportation, construction, logistic support, and production hardware, as well as development engineering. Planning cost and schedule estimates for investment and for operating the system for 5 years will be included.

(e) Identification of high-risk areas.

(f) Definition of intersystem and intrasystem interfaces and corresponding responsibilities.

(g) Evaluation of time-cost-performance trade-offs.

(h) Determination of firm and achievable Part I CEI Detail Specifications and Inventory Equipment Requirement Specifications.

(i) Validation of the technical approach for the total system cost which will lead to the formalized firm fixed-price (FFP), fixed-price incentive (FPI), or cost-plus-incentive-fee (CPIF) contract for the design and development portion of the Acquisition Phase.

(j) Identification of personnel and training requirements.

(k) Identification of the procedural data required.

The technical activities of the effectiveness process to be implemented during this phase will contribute directly towards achieving objectives (a), (b), (e), (f), (g), (h), (i), and (k), and indirectly towards (c), (d), and (j).

Application of the system and cost effectiveness technology during Contract Definition will provide the initial penetrating analysis of the inherent effectiveness potentials present in the selected weapon, support, or electronic system concept(s). Effectiveness analyses to be accomplished will shape design solutions for achieving the optimum balance of time, cost, and performance. Additionally, they will provide a detail management focus of the performance proficiency and economy of the system configuration by identifying the specific high technical and cost risk areas requiring further exploration, the system and subsystem performance and design parameters to be included in specifications, and the critical system parameters to be tracked and demonstrated during Acquisition. In general, the following implementation steps summarize the activities of the effectiveness criteria formulation, evaluation, and assurance process required during the Contract Definition Phase to provide this authoritative perspective:

- **Step E9 – Effectiveness Analysis Refinement** This activity is directed at refining and extending the system and cost effectiveness activities previously initiated on a gross basis in the Concept Formulation Phase.
- **Step E10 – Apportionment Analysis** This activity establishes the technical definition and traceability of the system performance and design requirements and subsystem allocations to be included in the System Performance/Design Requirements General Specification and the major Contract End Item (CEI) detailed specifications prepared and issued during this phase.
- **Step E11 – Effectiveness Progress Monitoring and Demonstration Planning** This activity establishes the essential system performance parameters and their expected convergence profile which are to be tracked during Acquisition as a fundamental effort of a Technical Performance Measurement program to determine the impact to the principal FOMs of variances in their values from planned values. As a related task, this activity defines the demonstration approach and the parameters to be demonstrated as evidence of the achievement of the FOMs during the Category I, II, and III testing and Technical Approval Demonstrations (TADs) to be conducted in the Acquisition and Operational Phases.

- **Step E12 – Reporting** This activity provides the compendium of the system and cost effectiveness criteria formulation, evaluation, and assurance results during the Contract Definition Phase to be included in the Proposed System Package Program (PSPP) document upon synthesis by the SPO of the best features of each design approach into an optimumly operable and economical system.

The degree that system and cost effectiveness requirements are to apply during the Definition Phase will be specifically set forth in the CFP/TDP or Statement of Work (SOW) baseline requirements documents. Typical requirements include:

- Establishment of the principal FOMs and their numerical values, if not provided in the RAD, System Performance/Design Requirements General Specification, or CFP/TDP. The principal FOMs are to be fully responsive measures of system performance with respect to the total set of mission objectives. In contrast, the preliminary FOMs established during Concept Formulation may have related only to specific subsets of the mission objectives. Such special purpose FOMs were useful as comparative criteria for distinguishing unique capabilities of the candidate system concepts, and for establishing their feasibility.
- Implementation of updated system effectiveness analyses to include analysis of the availability, dependability, and capability effectiveness parameters, specifically accounting for various significant system states and critical factors of influence.
- Implementation of updated cost analyses to include developmental, acquisition, operational, and maintenance costs in relation to system development and acquisition schedules.
- Implementation of a refined, composite cost effectiveness analysis to obtain an optimum balance of technical performance, cost, and schedule time.
- Apportionment of the principal FOMs and the constituent system parameters which make up the availability, dependability, and capability effectiveness parameter sets.
- Reporting of analysis results, progress monitoring planning, and demonstration planning, with supporting data.

These typical requirements presume the existence of formalized effectiveness criteria formulation and evaluation results from previous activities of the Concept Formulation Phase. However, prior results are not a prerequisite for procurement situations where it is expendient or judicious to defer full implementation of the effectiveness technology to the Contract Definition Phase (e.g., due to the immediacy of the program or insufficient definition during Concept Formulation).

The system and cost effectiveness activities to be implemented during Contract Definition is characterized by a continuous refinement and expansion of the initial, summary-level criteria formulation and evaluation elements of the Concept Formulation Phase to first and second system indenture levels on the preferred concepts selected for detail definition. This is a natural companion to the refinement and updating of design and performance details and definition which are progressively and concurrently accomplished under the system program management and systems engineering management processes during this phase. Both of these processes are evolutionary in nature and are represented in AFSCM 375-4 and 375-5, respectively, as a sequential series of finely-divided technical and management activities, typically iterated in part in each of the three subphases of Contract Definition.
To provide the proper technical perspective of the system and cost effectiveness process during this phase, and the necessary visibility of the true interactions of the three processes, a composite and non-iterative series of system program management and systems engineering management activities has been defined. These composite activities, representing a derivative of the system program management process of AFSCM 375-4 only (which, in itself, already is a first order integration of the more detail systems engineering management network and other program networks), are:

- Establishment of baseline requirements, including trade-off studies required to adequately define the system concepts
- Preparation and issue of the specification tree, the System Performance/ Design Requirements General Specification, and detail specifications on major CEIs.
- Preparation and issue of the program work breakdown structure (PBS).

- Preparation and issue of the SOW and Request for Proposal (RFP), and updating of the Definition Plan.
- Review, verification, modification, and expansion of design details by selected contractors to accommodate their design approach, including determination of detail performance and design requirements for operations, maintenance, test, and activation functions.
- Revision and expansion by the SPO and contractors of functional analyses, Requirements Allocation Sheets (RASs), Trade Study Reports, schematic diagrams, time-line sheets, and effectiveness models.
- Preparation and issue of initial test plan.
- Establishment of detailed end item, facility, personnel, and training requirements.
- System requirements review, technical evaluation, and baseline updating.

4-2 EFFECTIVENESS ANALYSIS REFINEMENT   Step E9

General

The effectiveness analysis refinement activity is addressed to the refinement and expansion of the gross results obtained in implementation Steps E1–E7, and documented in Step E8 during Concept Formulation. This information is directly available for use in the Definition Phase via the CFP/TDP, RAD, and other baseline documents to provide direction for the analyses and to illuminate areas requiring emphasis and refinement. Technical results and analyses that normally will require updating include the following:

- Mission analysis
- Specifying principal FOMs
- Performance requirements analysis
- Operational requirements analysis

- Effectiveness parameter selection
- Model structuring
- System and cost effectiveness analysis

The nature of the refinement and the specific extent, timing, and areas in which the refinements are to be accomplished will depend on the exigencies and particular definition needs of each program.

Mission Analysis

Descriptions of the specific objectives of the mission are to be updated to reflect the latest information on the terminal performance that is required to be achieved by the system under operational conditions. Correspondingly, the kinds, magnitude, and probability of occurrence of enemy threats currently expected, and projected to be present in the five year future, may require further confirmation and definition. The modifying influences of specific neutralizing capabilities of the system against the threats or combination of threats, as well as the survival requirements under battle and peacetime operational levels of man-made and natural environments, also will require more precise definition in terms of prescribed limitations. These limitations normally are to be prescribed as maximum, minimum, or nominal values, or nominal values with a permissive range of values.

The basic sources of accrued information needed to obtain the detail level of definition required for the mission analysis activity will principally be the updated RAD, intelligence studies, system planning studies, and analyses of the performance impact of complementary systems to be employed in conjunction with the planned system, as described in the baseline CFP/TDP. While it is expected that the specific mission objectives may require a penetrating reexamination if the Conceptual studies indicate over-conservatism or over-optimism of specific objectives, it also is not expected that the mission will be redefined solely to be compatible with the capabilities of the preferred systems. By maintaining a conservative, but acceptable, mission objective stance, a reduction in total system cost can be anticipated. Correspondingly, overly optimistic mission objectives can be achievable by merging capabilities of existing systems with the planned new system as one of the effective operational alternatives available.

As a result of defining in greater detail and in a more quantitatively precise frame the mission objectives and operational condition under which the objectives are to be achieved, the principal FOMs can be accurately formulated. Furthermore, an explicit technical correspondence can now be established between FOM statements and specific objective requirements.

Specifying Principal Figures of Merit (FOMs)

Principal FOMs are to be developed during Contract Definition as measures of the overall performance quality of the system being defined for acquisition. For this purpose, the principal FOMs are to be directly identifiable with the total set of mission objectives, and are to envelop the critical and measurable top-level performance parameters observable in the system. These system parameters normally will include any quantifiable mission requirements (or translation of requirements) which may describe the basic capabilities that the selected system is to possess.

Major baseline decisions are required in formulating the principal FOMs during the Contract Definition Phase, including the following:

- Means by which the FOMs are to be responsive to the technical considerations of multiple missions. Typical responsive approaches to this aspect of the FOM definition problem are (1) to develop an overall FOM compositing each system FOM or (2) to establish a rank-order of the FOMs in terms of their relative importance.
- Mapping by which a technical correspondence can be established between each FOM and the spectrum of critical system performance parameter which it composites.
- Extent to which the principal FOMs are to be quantitatively and descriptively apportioned to the major subsystems to accurately represent the restrictive performance contributions of each major subsystem to the principal FOMs.

To the extent practicable, quantitative values for each defined FOM are to be specified in the system specification, and included in the RFP to guide contractor definition

activities. The value to be specified for each principal FOM defined at the inception of the Definition Phase can be established through extrapolations of the effectiveness analysis results acquired during Concept Formulation. Each principal FOM defined and FOM value specified will require a re-examination at the conclusion of Definition Phase studies for possible revision prior to use in the next phase of Acquisition.

Performance Requirements Analysis

With the definition of the principal FOMs, the reassessment of mission goals and available resources, and the updating and detailing of the system operations functions to first and second levels by the systems engineering activities, a corresponding extension is required of the set of time-based tables and matrices comprising the performance requirements profile. The definition of the profile should be sufficiently complete to provide a technical mapping of each principal FOM to its corresponding set of required system and subsystem functions and critical design performance parameters to be associated with the functions. The gross system performance requirements profile available from the Conceptual studies will provide visibility of the areas requiring further detail trade-off studies to establish, refine, or confirm the critical system parameters and parameter values to be included. The updating of the profile is an iterative process for the purpose of providing a current system parameter reference frame for the effectiveness parameter selection, model structuring, and effectiveness analysis activities during this phase.

The basic input data required are the revised and expanded (1) time-lines, (2) functional diagrams depicting system requirements in functional terms, (3) schematic diagrams of design characteristics within and between each subsystem, (4) RASs relating functions to be performed by the system to the design requirements which must be satisfied to meet these functions, (5) trade-off study reports describing the comparative analysis and selection of alternative design approaches, (6) mission analysis and FOM descriptions, and (7) the RAD and CFP/TDP baseline documents. The primary technical contributions of the performance requirements analytical results are to provide the following:

- The basic technical traceability of the FOMs to system and subsystem design and performance parameters

- The principal benchmarks and reference frame for the updating of the dependability and capability effectiveness parameters, models, and effectiveness analyses.

- A documented compendium of parameter-accountable factor cause-and-effect relationships for each defined system level

Operational Requirements Analysis

Consistent with the extension of the performance requirements profile to lower system levels, a corresponding expansion of the operational requirements profile is to be accomplished. System and subsystem parameters and concepts associated with manning, operating, maintaining, and logistically supporting the system, which comprise the effectiveness parameter of availability, are to be defined in detail and quantitative values established. These include individual parameters which measure the performance characteristics of the following operational elements:

- Maintenance
- Employment
- Deployment
- Transportation
- Personnel
- Base and depot support
- Training
- Test and activation

Examples of operational availability measures, concepts, and parameters to be refined were presented previously in Table 3-3 of paragraph 3-5.

The basic inputs required to define and establish the system operational parameters are the revised and expanded (1) time-lines depicting ground operations, (2) RASs which identify personnel, training, training equipment, and procedural data requirements imposed by the equipment and facilities defined in the Inventory Equipment Requirements Specifications, (3) functional analyses of end-item maintenance functions for AGE and OGE, (4) maintenance design requirements, including maintenance personnel and training, from the maintenance RASs, (5) end-item maintenance sheets, (6) mission analysis and FOM descriptions, and (7) RAD and CFP/TDP baseline documents.

The updated analysis results on operational requirements are directly usable to provide the following:

- The basic technical traceability of the FOMs to system and subsystem design requirements for manning, operating, maintaining, and logistics support parameters influencing total availability, such as turn-around time, reaction time, or in-commission rate
- The principal benchmarks and reference frame for the updating of the vailability effectiveness parameter, models, and analyses
- A documented compendium of operational parameter - accountable factor cause-and-effect relationships for each defined system level

Effectiveness Parameter Selection

The performance and operational requirements analysis updating activities were directed at defining the total set of principal subsystem and system performance parameters. These parameters represent the measurable, or otherwise determinable, required outputs of system functions to be achieved as evidence that specific demands of the mission can be met. An initial, gross reduction of this total set of principal parameters to a restrictive subset of critical system parameters influencing effectiveness is made during Concept Formulation.

The criticality matrices and tables previously prepared are to be updated to include the top-level functional, specialty, and operational system parameters contributing significantly to the availability, dependability, and capability parameter sets of system effectiveness. The critical accountable factors, acting as input variables to the system parameters, also will require expansion and re-examination. These accountable factors normally will be the important output parameters of major subsystem functions contributing to principal system functions, and will define the design and performance requirements to be placed on the subsystems. It is expected that the criticality matrices will not require extension to the subsystem parameter level. Such an extension for all first-level functions would be extremely detailed. Also, the multiple interactions of accountable factors normally present at lower design levels would obscure the visibility provided by the criticality matrices and tables on the relative importance of critical system parameters and accountable factors to the FOMs.

For the purposes of trade-off optimization and apportionment analysis, a refinement and extension of the transfer functions to more accurately describe the functional cause-and-effect relationships of the critical accountable factors to their system and subsystem parameters will be required. For simplicity, however, transfer functions are to be established and documented only for top-level system and first-level subsystem functions, with all input accountable factors below the first level considered as a total ensemble, independent of the design levels with which they are associated. The synthesis method and analysis methods I and II are usable to determine the required combinations of inputs, transfers, and outputs. The synthesis method can be used to determine the transfer functions connecting inputs with outputs if the inputs and outputs requirements are known or can be reasonably postulated. This method was previously described in Chapter 3 and summarized in Table 3-4. Analysis Method I can be used to determine the performance outputs if the characteristics for the inputs and how they are operated upon (transfer functions) are known. Analysis Method II addresses the reverse problem of determining accountable factor inputs for known performance outputs and transfer functions. The general characteristics of the three methods are outlined and compared in Table 4-1. Further details on these methods are described in Appendix A.

Each transfer function relating a system performance parameter to its accountable factors can be represented by an analog diagram with transformed mathematical functions. Additionally, for time-varying systems which are linear (or suitably linearized with a method such as perturbation), each transfer function can be represented by an adjoint analog. Examples of such systems are closed loop systems, feedback systems, and similar null-seeking systems. The adjoint analog is obtained by reversing all inputs and outputs and generating all time-functions backwards. For example, if a system analog has 3 inputs and 1 output, then the system adjoint must have 1 input and 3 outputs.

Adjoint analysis is a special case of Analysis Methods I and II and is usable as a preliminary design technique to statistically analyze and optimize linear, time-varying systems. The method employs parameter variation analysis commonly used by system developers.

TABLE 4-1 COMPARISON OF SYNTHESIS AND ANALYSIS METHODS

Characteristic	Synthesis Method	Analysis Method I	Analysis Method II
• Phase normally applicable	Concept Formulation and Contract Definition	Contract Definition and Acquisition	Contract Definition and Acquisition
• Relative ease of application	Difficult	Simple	Difficult
• Relationship of variables*	Transfer functions are implicit functions of inputs and outputs	Outputs are explicit functions of inputs and transfer functions	Inputs are implicit functions of outputs and transfer functions
• Information needed to start preliminary design	Minimum amount. Requires knowledge of inputs and outputs. Then find transfer functions	More than synthesis method. Requires knowledge of inputs, system functions, transfer functions, and configuration details on subsystems and equipment. Then find outputs	More than synthesis method. Requires knowledge of outputs, system functions, transfer functions, and configuration details on subsystems and equipment. Then find inputs
• Input-output expression for linear, time-varying systems	Provided by a superposition integral	Provided by same superposition integral	Provided by same superposition integral
• Procedure	Find transfer functions to satisfy superposition integrals. Then find physical characteristics of system which satisfy transfer functions	Iterative application of superposition integrals by changing inputs repeatedly, which alters form of transfer functions until outputs are obtained	Iterative application of superposition integrals by changing outputs repeatedly, which alters form of transfer functions until inputs are obtained

*Inputs and outputs normally are in the form of time-functions.

TABLE 4-1 COMPARISON OF SYNTHESIS AND ANALYSIS METHODS (Continued)

Characteristic	Synthesis Method	Analysis Method I	Analysis Method II
• Optimizing procedure (example)	Find transfer function such that the difference (error) between each output and the true output is as small as possible, using this transfer function	Find outputs such that the difference (error) between each output and the true output is as small as possible, using the known transfer function	Find inputs such that the difference (error) between each output and the true output is as small as possible, using the known transfer function
• Error criterion (example)	(1) minimum time – averaged squared difference or absolute difference, or (2) minimum expected value of squared difference	Same as (1) and (2) of Synthesis method	Same as (1) and (2) of Synthesis method
• Solution method for simple, linear time-varying systems	Determine transfer functions using vector analysis, matrix theory, and Laplace transforms, for example	Determine outputs by solving differential equations or evaluating integrals connecting outputs to inputs	Determine inputs by solving differential and matrix equations connecting inputs to outputs
• Solution method for complex, linear and non linear time-varying systems	Combination of numerical and analytical procedures using digital computations	Same as for Synthesis method	Same as for Synthesis method
• Special technique to facilitate solution for linear, time-varying system	No simple method	Adjoint method	Adjoint method

With the expansion and detail definition of the principal transfer functions, the sensitivity functions previously developed on a gross basis can be updated at the system level and expanded to the first-level. This will provide the insight into the lower-level trade-offs required for an optimum balance of cost and performance and the detail design requirements for major CEIs. The results of the sensitivity analyses for the system parameters are used to revise the normalized sensitivity coefficients and accountable factors to be included in the criticality matrices.

The basic data required to revise and further define the system and subsystem parameters and accountable factors critical to system performance and operations are (1) the functional diagrams and related RASs and time-line sheets, (2) the performance and operational requirements profile, (3) end-item maintenance sheets and related maintenance RASs, (4) the initial system specification, and (5) the RAD and CFP/TDP baseline documents. The results of the updated selection of effectiveness parameters are directly usable to refine the effectiveness models to be applied for evaluation, optimization, trade-off, and apportionment of the FOMs, effectiveness parameters, and system performance parameters composited by the effectiveness parameters and FOMs.

Model Structuring

System models developed and employed during Concept Formulation for the evaluation of the preliminary FOMs will require updating for use in the evaluation of the defined principal FOMs. The principal FOMs may not correspond necessarily to the preliminary FOMs. Additionally, the need for the system FOM and cost effectiveness models for Contract Definition to provide an accurate and realistic analog of the system's cost and performance behavioral characteristics will precipitate a necessary revision and expansion of the previously established system models. The model structuring updating activity normally will include the following:

- Review and reassessment of previous assumptions used, including the explicit rationale and justifications for the assumptions. Refine and modify assumptions based upon the current knowledge of design and performance details. List all such assumptions, rationale, and justifications.

- Expansion of the limited system state model, normally a two-state analysis model formulated during Concept Formulation to a larger, but manageable number of state groups that will realistically represent the significantly different operating conditions that the system may be in during its mission assignment. State groups are to be defined and established where measurably different mission outcomes are present, and the associated probabilities can be realistically and validly estimated. On this basis, and consistent with the design details being evolved, the states to be defined for an effectiveness analysis are to be responsive to the system operating conditions of (1) fully operable (mission not aborted), (2) fail-operable (system failures, but mission not aborted), and (3) inoperable (abort). For the fail-operable system condition, a mosaic of mission outcomes is possible. However, this spectrum normally is analytically manageable. The fail-operable system condition includes the different outcomes for definable combinations of failed major equipment and their associated functions that (1) are redundantly present, (2) represent extra performance margins, (3) possess over-ride alternatives, or (4) will not materially reduce capability. The fail-operable system operating condition can be partitioned into a discrete, limited number of states corresponding to equipment failure combinations with similar magnitude of effectiveness influence. A partially failed system operating condition is synonymous with the condition of fail-operable. Any condition less than this is considered inoperable, and hence of zero capability.

- Development of a state flow diagram to represent the progression of the multiple system states during the mission. This diagram is to be time-based and responsive to any partitioning of the mission into discrete time intervals for separately, definable mission tasks or events. An example of a three-state flow graph is shown in Figure 4-1.

- Validation, revision, and expansion of the probability estimates for each of the defined system states appropriate at the begining, and at the end of the mission. These estimates can be extrapolated from sources such as historical data from similar or related systems, data in MIL-HDBK-217 and RADC Reliability Notebook, random sampling simulations, and theoretical analyses.

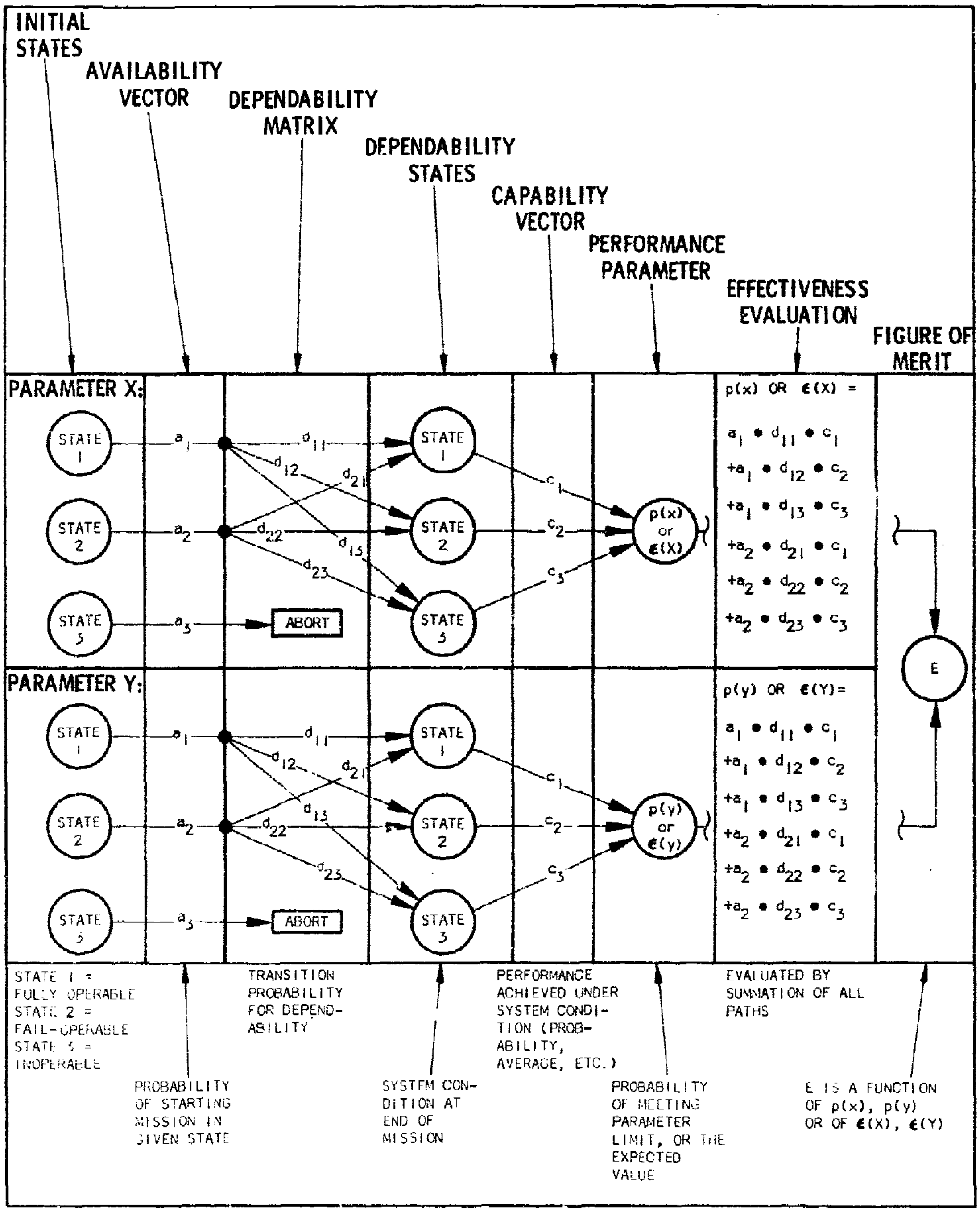


Figure 4-1	System Effectiveness Three-State Flow Graph	Page 4-17

- Re-examination and definition in detail of the technical scenario for the evaluation, including the distinct levels of threat groupings expected to be present for each mission. The threat groups are to be composited so as to represent significantly different effects that are expected on the magnitude of capability achievable by the system.

- Formulation, refinement, and expansion of the system effectiveness models to be used for the evaluation of the principal FOMs defined for the system, and the translated FOMs defined for major subsystems. The models are to take into account the effectiveness parameters of availability, dependability, and capability. These parameters typically will represent a technical integration of all the principal system performance, technical specialty, and operational parameters of the system that will critically contribute to the magnitude of an FOM achievable. Submodels will be required for each of the three effectiveness parameters to provide the technical logic of how the included assemblage of critical parameters are related. Additionally, for each critical system parameter composited by the effectiveness parameters, a separate model is to be formulated for use in its evaluation. These system parameter models normally will be coincident with the transfer functions that mathematically relate an output system parameter to its ensemble of critically dependent first-level accountable factors. The transfer functions typically can be applied in analytical, statistical, or simulation analyses.

  Refinement and updating of the system cost model. The cost models are to take into account the phase-related categories of development, acquisition, and operational and maintenance resource costs (commodity size, technology, and dollars) on a total program basis spanning the useful life of the system complement. Submodels also are required to provide the cost relationships of these broad aggregations of cost to their major categories, such as those previously listed in Table 3-9 of paragraph 3-7, Chapter 3, for the Concept Formulation Phase. The submodels are to be suitable for integration into the total system cost model. An alternate to the developmental, acquisition, and operational and maintenance categories of cost could be the Level I breakout of cost elements from the Program Work Breakdown Structure (PBS). Examples of such cost categories are RDT&E, system procurement, military construction, operations and maintenance, military personnel, other procurement, etc. These categories can be

directly correlated with the broad phase-related categories, if such a correspondence is desired for cost estimating purposes. Where the PBS is used as a basis for categorizing costs to be integrated by the system cost model, the cost relationships are to be defined to Level III of the PBS as a minimum. This level normally will include the detail work effort and contractor effort. Additionally, contractor cost relationships associated with his Work Breakdown Structure (WBS) are to be defined for at least the next lower summary level of cost categories. System cost estimates normally will represent a composite of inputs from participating commands, such as the using command, ATC, AFLC, and AFSC. These inputs in part are based on data provided by the involved contractors, with contractor estimates obtained through responses to the RFP and the studies contracted for during this phase. Methods to be used for cost sensitivity and variance analysis to provide a measure of the precision of the cost data are to be defined in detail as a part of the model structuring refinement activity. Examples of techniques useful for cost precision analysis are the cost variance and PERT-Cost procedures.

- Reformulation of the cost effectiveness models as necessary and refinement of the cost effectiveness criterion for each mission. Identification from the design details being expanded concurrently of the significant trade-off alternatives for the accountable factors, system parameters, and system functions. Determination of the technical constraint boundaries and the resource costs associated with each alternative, or each set of intersecting alternatives.

- Establishment of detail requirements for input data which are fundamental to obtaining an analytical or simulated output for each system and subsystem effectiveness, cost, and cost effectiveness model defined. Table 4-2 provides a listing of the typical input data requirements to be defined and the expected outputs which can be derived from this data by application of the transfer functions incorporated in the models. Additionally, a data guide is to be prepared to document data sources which are to be used for effectiveness analyses, including existing sources and those supplemental sources expected to be available and utilized during later acquisition and operational phases.

TABLE 4-2 TYPICAL INPUT REQUIREMENTS AND MODEL OUTPUTS

Input Data Requirement	Output Estimate
• Distribution or discrete range of values for each critical accountable factor (design variable)	Distribution of values for each system performance parameter critically contributing to the capability effectiveness parameter set.
• Failure rates, failure modes, redundancies, alternate modes of operations, and in-operation maintenance, repair, and adjustment rates.	Distribution of values for system reliability parameter of the dependability effectiveness parameter set.
• Exposure time and reaction time distributions, dispersal radius, hardening level, alternate modes of initiation, threat levels and patterns expected, and mobility.	Distribution of values for system survivability parameter of the dependability effectiveness parameter set.
• Operational schedules, number of available systems, assets available, time between inspection, checkout time, checkout failure rates, inventory fill rates, removal rates, time required for maintenance, transportation time, deployment mode, and characteristics of complementing systems.	Distribution of values for system availability effectiveness parameter. Also suitability of equipment spares, maintenance and handling facilities, and manpower allocations.
• Probability of occurrence and time distributions for critical maintenance items, maintenance frequency and time duration by type of items, maintenance assets of personnel, skills, equipment, and types of facilities, maintenance activity sequencing for minimum downtime, mean turnaround span for each item, and delays.	Distribution of values for maintenance, deployment, transportation, personnel, base and depot support, training, and test and activation system parameters of the availability effectiveness parameter set. Also optimum maintainability policy (e.g., level of maintenance which maximizes reliability gain per unit cost).
• Resource cost of commodity size (skills, material, facilities, etc.), technology, and dollars per mission.	Expected total and per year system life cycle cost per mission.
• Output estimates for system availability, dependability, capability, and cost parameters.	Distribution of values for system and cost effectiveness measures.

System and Cost Effectiveness Analysis

System and cost effectiveness analyses are to be updated and to be conducted on a more refined basis consistent with the amount of design details being defined for the system. Each effectiveness parameter included in the established models is to be analyzed with respect to the specific influences and trade-off potentials of critical accountable factors and effects of threats on the composited system parameters. The ultimate output of these analyses is to technically establish and define in detail a system configuration with optimum performance and cost balance. Specific analyses required during this phase include the following:

- Trade-off analyses of vital design alternatives to provide design visibility and authoritative knowledge of (1) the high technical and cost risk areas requiring configuration decisions to reduce such risks to sensible ones, (2) the interactive influence of alternate design details and functions on each FOM and its effectiveness parameters, and (3) the gross magnitude of effectiveness improvement achievable in each configuration analyzed.

- Analyses of critical accountable factors to analytically determine their specific range of required values for maximum effectiveness. These analyses are to include a refinement and more accurate determination of the sensitivity functions relating incremental changes in values of these accountable factors to changes in effectiveness parameters and FOMs. The criticality matrix is to be updated as a result of this analysis.

- Analyses of the defined system states to exclude those states and considerations which are least critical to the mission for model simplification. Analytical, statistical, and mathematical simulation techniques can be used to derive the reduced critical state set.

- System effectiveness analyses to provide an estimate for each defined FOM measure. These estimates are usually derived from a sequence of optimization iterations. (A typical optimization technique to employ is the Analysis I method. previously described in this paragraph, with a forward and backward optimization procedure after terminal design constraints have been met from previous iterations. On a forward pass, which is the improvement pass, the output is determined. The adjoint equations then are solved on the backward pass using the improved output values.) Analyses of system effectiveness are to be performed separately for the availability, dependability, and capability parameters. Availability analyses are directed at defining and evaluating the

condition or readiness of the candidate system configuration at the beginning of an assigned mission. Updated probability estimates for each state which is defined as critical are to be established and used for this analysis. Dependability analyses are addressed to an evaluation of the operating conditions of the system during and at the end of the mission for each defined availability state. Transition and outcome probability estimates will be needed to assess this parameter. Capability analyses, which are performed to evaluate the output of the critical system performance parameters, also will be required. For each system parameter, the output value corresponding to each of the different dependability states is to be estimated.

- Cost analyses to determine the cost of each major performance or operational alternative to be analyzed.
- Cost effectiveness analyses to establish the optimum performance, time, and cost balance.
- Statistical analyses to establish or refine the lower confidence estimate for each FOM and cost effectiveness measure, taking into account, as a minimum, statistical errors, assumption errors, and cost variances.

Analyses are to be performed and estimates tabulated for each mission and for the most probable and worst level of threats. Estimates are to be provided on a current and 5-year projected basis for the measures of cost effectiveness, FOMs, effectiveness parameters, and critical system parameters.

Information Flow

The basic data required for the effectiveness analysis refinement activity are principally available from the following activities, most of which are progressively updated throughout the Definition Phase:

- Baseline requirement documents defining system concepts
- CFP/TDP and RAD
- Effectiveness report of Concept Formulation Phase
- Program work breakdown structure

- Detail performance and design definition studies
- Functional analyses, RASs, tradeoff studies, schematic diagrams, and time-lines.

The outputs of this activity will contribute to the following:

- Establishment and validation of firm and achievable system specification, CEI detail specifications, and Inventory Equipment Requirement Specifications
- Definition of intersystem and intrasystem interfaces
- Identification of high performance and cost risk areas
- A basis for the preparation of augmenting and compatible program plans for the specialty technical disciplines
- Validation of the technical approach and creation of the best cost-effective system
- Identification of personnel and training, logistics support, and other operational requirements
- Identification of data requirements.

A summary of the basic information network for the effectiveness analysis refinement activity is shown in Figure 4-2.

4-3 APPORTIONMENT ANALYSIS Step E10

General

The apportionment of system effectiveness measures and their influential parameters is a technical process which must be implemented if the system design criteria to be established are to be consistent with the required system performance to meet mission objectives. System effectiveness measures normally to be apportioned during the Definition Phase include FOMs, their constituent parameters of availability, dependability, and capability, and critical system parameters (whose apportioned first-level accountable factors become the top design parameters of major CEIs). Apportionment can be technically considered as being a direct result of an optimization procedure. Generally, apportionment is accomplished by establishing with an iterative procedure the ensemble of input values which will provide the required balance

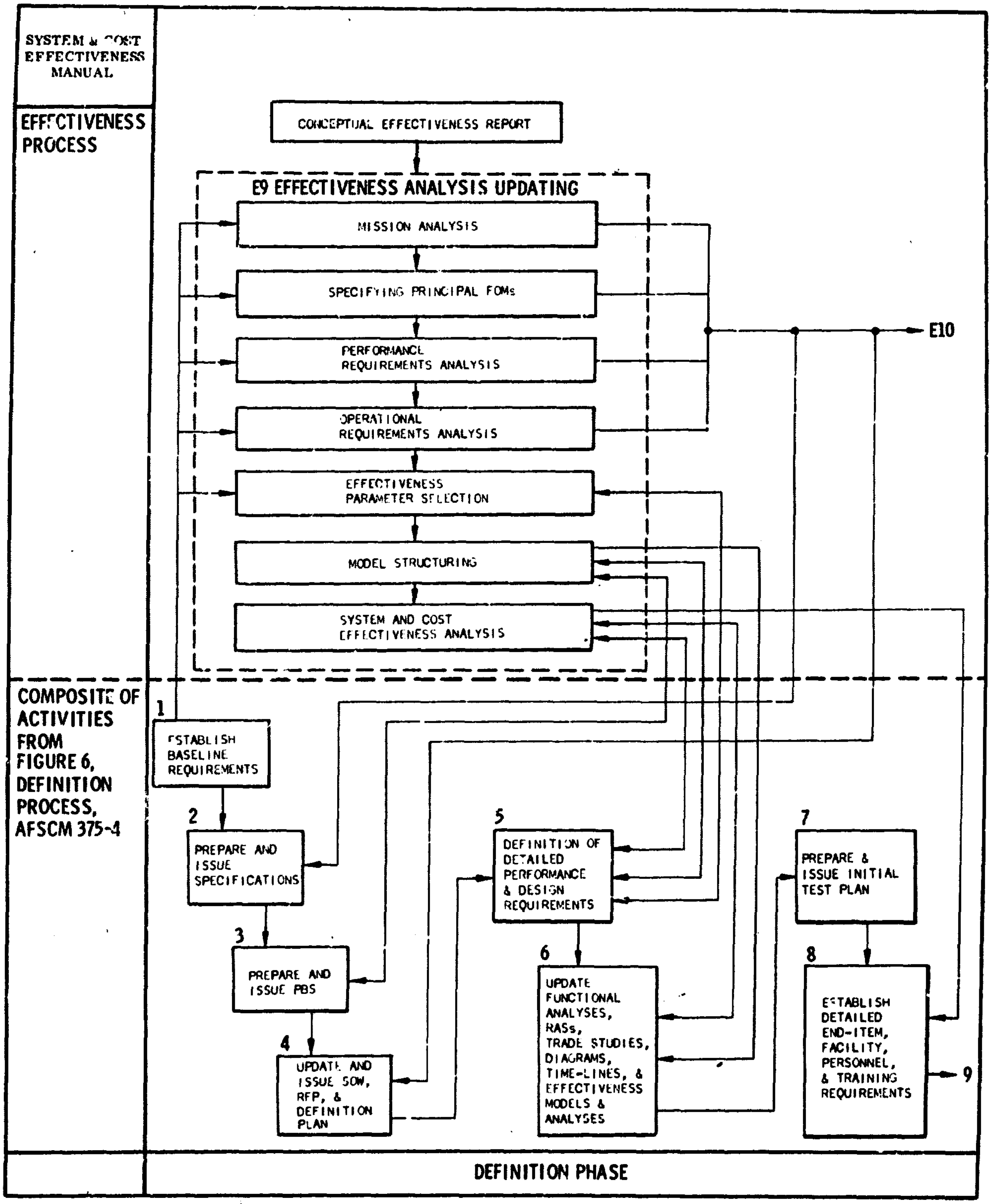


Figure	Effectiveness Analysis Refinement Information Network	Page
4-2		4-24

of optimum output values for the FOM and cost measures. Traditionally, apportionment implies a rational allocation of an output to its ensemble of inputs. In practice, the rational basis for such a top-level to lower-level allocation is to build from the lower-level design details up through transfer functions to the top-level. This building process involves an oscillating series of allocations and adjustments of allocations until achievable, optimum values for the accountable factors are determined which will optimize the output terminal parameters. Having thus optimized the input design variables with respect to the FOMs, the technical connections between these variables and the FOMs, such as system and effectiveness parameters, will in turn be compositely optimized.

Apportionment of FOMs

The apportionment of each principal FOM defined for an overall weapon, support, or electronic system configuration is a two-step process that can be accomplished typically as follows:

- Translate each top-level system FOM into a set of lower, first-level sub-FOM measures. As a minimum, this is to be accomplished for each major subsystem. The sub-FOMs must be capable of being technically described in terms of specific subsystem performance parameters that are observable and measurable. A sub-FOM, therefore, represents an integration of a restrictive set of terminal performance characteristics associated solely with a first-level subsystem (or a major CEI depending on the point of reference). It is a measure of the performance value or merit of the subsystem with respect to its contribution to the performance value or merit of the overall system. Each sub-FOM also must possess a technical link-up with the system FOMs, such as by contributing or being identical with a defined system parameter, or by contributing to a set of system parameters. One of these two technical connections usually is present, and can be represented by a performance-oriented logic diagram. In a similar manner, a companion connection exists between the availability, dependability, and capability effectiveness parameters of a subsystem (integrated by a sub-FOM) and the effectiveness parameters of a system composited by a system FOM. An overview of the technical relationship of a subsystem FOM to its system FOM is shown in Figure 4-3. Additionally shown is a perspective of how their associated performance parameters are integrated by these FOMs.

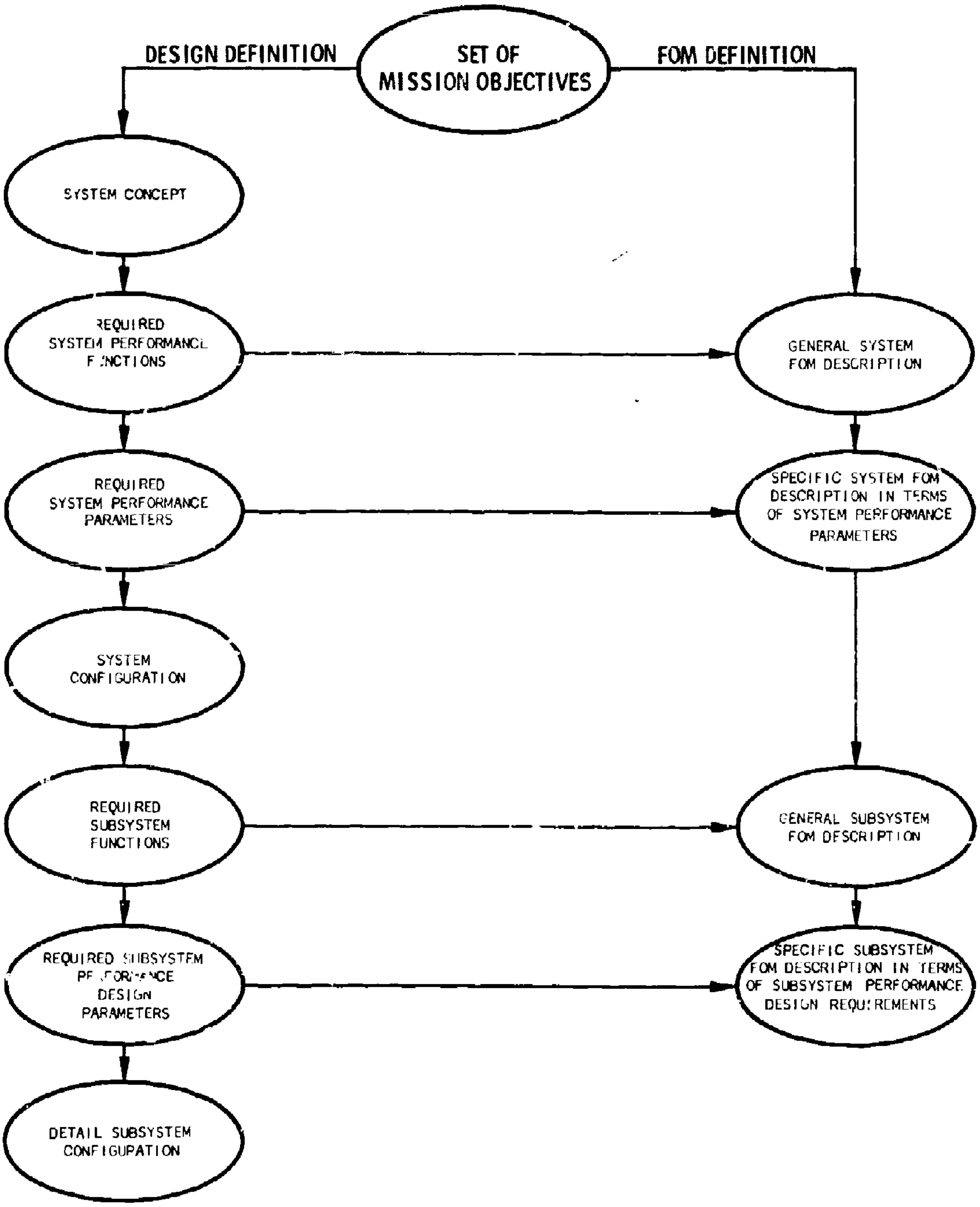


Figure 4-3	Relationship of Subsystem and System Figures of Merit	Page 4-26

- Numerically allocate an overall system FOM to its defined sub-FOMs. The technical analog of the connection between the sub-FOMs and the system FOM, just described, will indicate the system and subsystem parameters to be included in the apportionment analysis. Techniques for the numerical apportionment of system FOMs include (1) Lagrangian method, (2) Lagrangian method with priority lists, (3) dynamic programming, (4) direct comparison (direct search), (5) linear programming, (6) gradient projection, and (7) calculus of variations. These techniques are equally applicable for the apportionment of system effectiveness related measures of availability, dependability, capability, and system parameters. A guideline for selecting the technique to use for a particular application is provided in Table 4-3. Appendix D summarizes the detail procedure for each of these techniques.

Apportionment of System Parameters

The terminal performance and operational behavior of a system are observable and measurable by its top-level system parameters. Along with the system FOMs, these output parameters represent the focal point of most optimization processes. The best combination of input values for critical accountable factors within resource or requirement constraints which will optimize these parameters is to become a part of the top design criteria for major CEIs. A branching of the apportionment process to lower-level accountable factors normally will not be required during the Definition Phase.

An input accountable factor may not be in the same measurement unit as the system output parameter(s) it influences. This is typical of many functional parameters composited by the capability parameter. In most cases where this situation is present, there is an analytical connection of the different measurement units through transfer functions. On the other hand, accountable factors may have the same measurement unit as their output parameters such as those which normally are summed or multiplied (e.g., error, weight, lift, drag, probabilities, and turnaround time). Examples of both accountable factors with different measurement units than the system outputs they influence, and those with the same input-output measurement units are listed in Table 4-4.

TABLE 4-3 APPLICATION GUIDELINES FOR SELECTED APPORTIONMENT TECHNIQUES

APPORTIONMENT TECHNIQUE PROCEDURE

1. Lagrangian Method – Maximize difference between output* and sum of constraint variables.
2. Lagrangian Method With Priority Lists – Add priority numbers to determine optimization path.
3. Dynamic Programming – Optimize one stage of problem at a time.
4. Direct Comparison (Direct Search) – Compare output* for each alternative.
5. Linear Programming – Optimize output* based on a system of linear constraint functions.
6. Gradient Projection – Modify optimization vector with constraint components.
7. Calculus of Variations – Formulate optimizing criterion as an integral.

Characteristic	Apportionment Technique Applicable**						
	1	2	3	4	5	6	7
• Simple to understand				X	X		
• Fast to accomplish		X				X	
• Provides perspective of optimization		X					
• May require computer	X		X	X	X	X	X
• Concept Formulation				$\boxed{X}$			
• Definition	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$		$\boxed{X}$
• Acquisition	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	X	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$
• Many system inputs	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$		$\boxed{X}$	$\boxed{X}$	$\boxed{X}$
• Few system inputs	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	X	X
• Few values for each system input	X	X	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	X	X
• Continuous system inputs	$\boxed{X}$	$\boxed{X}$	X	X	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$
• System inputs do not interact	X	$\boxed{X}$	$\boxed{X}$	X	X	X	X
• Linear transfer functions	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	X	X
• Nonlinear transfer functions	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$		$\boxed{X}$	$\boxed{X}$

*If output is Figure of Merit, inputs may be system parameters or accountable factors

**X denotes applicable; $\boxed{X}$ denotes applicable and preferred

TABLE 4-4 EXAMPLES OF ACCOUNTABLE FACTORS AND PARAMETERS WITH DIFFERENT AND SAME MEASUREMENT UNITS

Parameter (Unit)	Accountable Factor (Unit)*
	Different Units
• System time of flight (minute)	Pitch command (degree) Cutoff velocity (f.p.s.) Aerodynamic coefficients (---) Re-entry ballistic coefficients (---)
• System range (mile)	Payload (pound) Total impulse (pound-second) Pitch program (degree)
• System accuracy (yard)	Thrust offsets (inch) Time to cut-off (microsecond) Wind perturbations (f.p.s.) Guidance alignment (milliradian)
	Same Units
• System weight (pound)	Subsystem weight (pound)
• System probability of maintenance (percent)	Subsystem probability of maintenance (percent)
• System probability of performing function (Reliability) (percent)	Subsystem probability of performing function (Reliability) (percent)
• System lift (count)	Subsystem lift (count)
• System drag (count)	Subsystem drag (count)
• System error (feet)	Subsystem error (feet)
• System turnaround time (hour)	Subsystem turnaround time (hour)
• System volume (inch^3)	Subsystem volume (inch^3)
• System computer capacity (bit)	Subsystem computer capacity (bit)
• System probability of safety (percent)	Subsystem probability of safety (percent)
• System gain (volt)	Subsystem gain (volt)
• System impulse (pound-second)	Subsystem impulse (each stage) (pound-second)

*All critical accountable factors are not exhaustively listed for each system parameter.

Apportionment of Effectiveness Parameters

Optimization of an FOM invariably can be accomplished through two technical paths. These are:

- By optimizing the first-level critical accountable factors with respect to the FOM, thereby optimizing the top-level system parameters with respect to the FOM.
- By optimizing the top-level system parameters directly with respect to the FOM.

It is also possible to take a direct path from lower-level factors. However, this path is not technically feasible during Contract Definition because of the potential absence of design details and definition at lower design levels and the lack of knowledge of the precise effectiveness influences from the numerous interactions of accountable factors present at these design levels. Another possible but technically undesirable path is by directly optimizing the effectiveness parameters of availability, dependability, and capability with respect to an FOM. Since these parameters typically are parameter sets which are inclusive of multiple system parameters, their direct optimization would not provide any intelligence as to the specific design requirements for the system parameters and their accountable factors for optimum effectiveness.

The need to separate out the apportioned values for availability, dependability, and capability, apart from their utility in an effectiveness analysis, normally will arise only if it is desired to include these parameter sets into system and subsystem performance specifications. In practice, it is not expected that this will be universally required, except in special applications where these parameters are of critical consequence, and thus have been traditionally included in specifications. An example is the specification of system availability for aircraft, booster, electronics, and missile systems and for training missions. Another situation where it may be desirable to include the availability, dependability, and/or capability parameters in specifications is where a trade-off option is available for the system developer to establish the best combination of system parameter values composited by each effectiveness parameter, subject to a required value for the effectiveness parameter. A variation of this situation is where it is desired to control both an effectiveness parameter (such as the capability parameter) and a restrictive group of critical, high risk parameters by specifying values only for the controlled parameters. The open design option would then apply to the values for the balance of the less critical parameters integrated by the effectiveness parameter.

Procedure

The procedure for the accomplishment of the apportionment analysis activity can be summarized by the following general steps:

- Translate each top-level FOM into a set of sub-FOM measures for each first-level subsystem.
- Establish the technical connection of each sub-FOM to the system FOM. Represent this link-up with a performance-oriented logic diagram.
- Numerically allocate an FOM to its sub-FOMs through the defined technical connection of the sub-FOMs to the system parameters which they may influence. Also allocate (1) the sub-FOMs to their subsystem performance parameters, (2) the system performance parameters to their critical first-level accountable factors, and (3) optionally, the system FOMs to their effectiveness parameters of availability, dependability, and capability. Accomplish the apportionment using techniques such as those delineated in Table 4-3 previously described.

Information Flow

The basic data required for the apportionment analysis activity include the following:

- Specific descriptions of principal FOMs and sub-FOMs
- Initial performance requirements from the system specification
- Mission, performance, and resource constraints from the system specification and baseline documents
- Mission operational conditions (enemy threat levels, natural environments, etc.) from baseline documents and the effectiveness analysis refinement activity
- First and top-level transfer functions (including sensitivity functions) and criticality matrix from the effectiveness parameter selection activity.
- Initial input-output nominals for design parameters selected from trade-off and deterministic optimization studies from the effectiveness analysis refinement activity.

The basic outputs of this activity are used to validate the technical approach and to establish realistic and firm design requirements for performance parameters to be included in the updated system performance specification and detail specifications for

major CEIs. A firm technical basis is, therefore, provided on design criteria which will lead to the development of an optimum performance-and cost-effective system. Figure 4-4 summarizes the information network for the apportionment analysis activity.

4-4 EFFECTIVENESS PROGRESS MONITORING AND DEMONSTRATION PLANNING $\boxed{\text{Step E11}}$

General

A program will be required to be defined during Contract Definition for the monitoring of effectiveness progress, and the approach and procedures to be used for demonstration of current effectiveness achievement during later Acquisition and Operational phases. The early planning of this program will insure the availability throughout later phases of the following:

- A timely, integrated, and continuous status of current, planned, and demonstrated system performance. This visibility will provide a valid and rational basis for SPO and contractor management decisions on critical or sensitive design and program areas requiring correction of deficiencies.
- Necessary and timely tests, test data, and analytical and simulation studies for use in (1) assessing current effectiveness status, (2) predicting future performance progress, (3) development of more realistic target values for FOMs and system performance parameters, and (4) demonstration of effectiveness.

The system's current performance value is the terminal, measurable behavior that is expected to be observed if the system is to be operated on the date of the estimate. The planned performance value is the anticipated value of a parameter at a designated point in the development cycle and will reflect predicted engineering changes and future expected progress. The demonstrated performance value is that observable from actual operational performance tests normally associated with Category III testing and Technical Approval Demonstration (TAD) testing (or Category I and II system testing if the TAD equivalent is performed during such tests). A planned performance value if accurately estimated will converge to the demonstrated performance value.

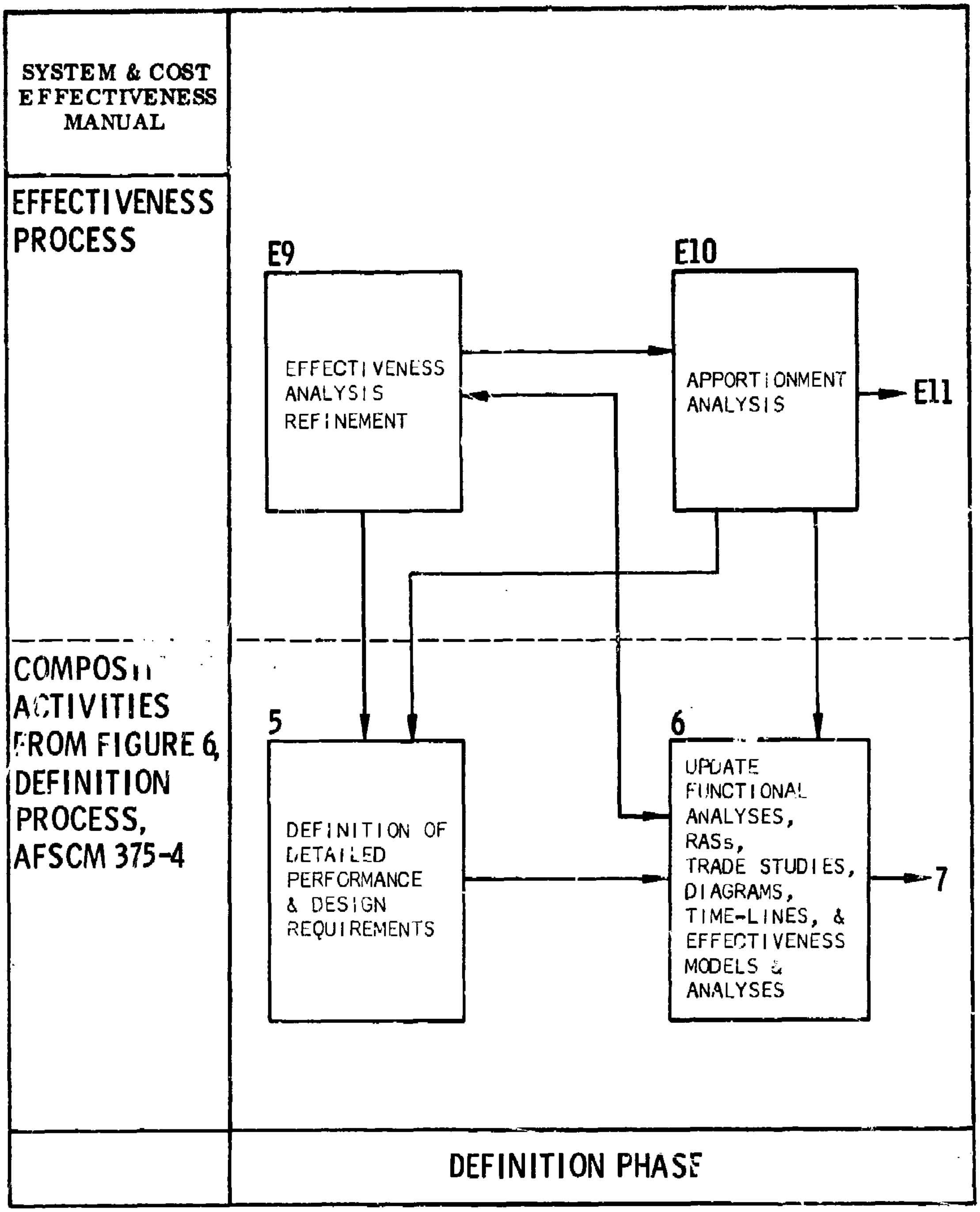


Figure 4-4	Apportionment Analysis Information Network	Page 4-33

Effectiveness Progress Monitoring

A defined plan for monitoring effectiveness progress during Acquisition and Operational Phases should include a series of dynamic elements to be accomplished in a timely and technically acceptable manner. The plan is to include the basic approach, implementation guidelines, and methods for its accomplishment. In line with the integrating aspects of the system and cost effectiveness technology, such a plan should be responsive to the outputs of the multi-specialty disciplines affected. For the effectiveness monitoring program to be efficient, fundamental features must be incorporated. These include (1) simplicity in implementation, (2) technical sufficiency, (3) flexibility so that critical and sensitive design areas which are rotating with time can be highlighted, (4) maximum utilization of existing data, and (5) non-duplication with other complementary plans, except on a top summary level.

As a part of the plan for monitoring effectiveness progress, an efficient system is to be defined for the regular assessment of technical progress in meeting system performance parameter requirements and goals throughout the Acquisition Phase. The system should be planned with observant care of the following practical realities:

- The status of an FOM value and the value for each of its effectiveness parameters of availability, dependability, and capability normally cannot be directly tracked. These are composite values, determinable through analytical calculations. In contrast, the system parameters, first-level parameters, and accountable factors are directly tractable in that they represent the measurable, terminal performance characteristics of a system and its constituent subsystems.
- Only parameters and accountable factors critical to the performance and cost effectiveness of a system are to be tracked.
- Technical performance measurement and tracking of critical parameters and accountable factors is a dynamic process, wherein each element may rotate in time with respect to its criticality. Thus, a critical parameter should be reduced in stature to a non-critical parameter and deleted from the tracking system it its target has been achieved and is not expected to be altered with anticipated design changes.

A necessary entity of a technically sufficient monitoring plan on effectiveness progress and growth is a system for the meaningful measurement of progress in meeting target values for the system performance parameters. Such a system is defined as a Technical Performance Measurement (TPM) system. Elements to be included on a preliminary basis in a TPM system, consistent with the amount of design details and configuration definition available during the Definition Phase, include:

- Master list of parameters and accountable factors to be tracked. Table 4-5 provides examples of such items.
- Planned convergence profile for each parameter and accountable factor listed. As a minimum, an estimate of the current performance value at the start of development, and the planned value at the time of system delivery, are to be included.
- Format for reporting of status on the current, planned, and demonstrated parameter values achieved and assigned, such as:

  (1) Parameters and accountable factors from the master list which are to be reported to the procuring agency. This normally will involve top-level and some first-level system parameters

  (2) Frequency of reporting. Typical program points for reporting are those which coincide with the planned SPO review of the contractor's integrated systems engineering and technical direction efforts. These SPO reviews are addressed to determining contractor progress and technical adequacy in meeting system requirements, including effectiveness considerations. Typically, these points are the system requirements reviews, preliminary design reviews (PDR), critical design reviews (CDR), first article configuration inspection (FACI), acceptance tests, and TADs.

  (3) Approach for highlighting current and anticipated critical problem areas, and the nature of problem analysis summaries to be presented.

  (4) Approach for filtering of design changes affecting the parameters and factors on the master list.

TABLE 4-5 EXAMPLES OF CANDIDATE PARAMETERS FOR INCLUSION IN A TECHNICAL PERFORMANCE MEASUREMENT SYSTEM*

Mission

- Basic long range mission
- Basic payload mission with specified g load factor
- Maximum payload mission with specified g load factor
- Re-supply mission

System and First-Level Parameter

- Liftoff weight
- Takeoff distance
- Rate of climb (gear up)
- Initial cruise altitude
- Cruise speed
- Payload
- Range
- Empty weight
- Operating weight
- Operating weight center of gravity
- Takeoff drag
- Cruise drag
- Landing drag
- Takeoff maximum lift coefficient
- Landing maximum lift coefficient
- Installed takeoff thrust
- Installed climb thrust
- Installed cruise thrust
- Maximum reverse thrust
- Installed cruise thrust specific fuel consumption
- Abort reliability
- Mission reliability
- Maintainability
- Organizational level maintenance manhours
- Depot level maintenance manhours
- Field level maintenance manhours
- Inspection time
- Safety
- Quick engine change time
- Preventive maintenance time
- Corrective maintenance time
- Structural limit weight at specified load factor
- Fuel capacity
- Roll in one second
- Air minimum control speed
- Roll helix angle
- Lateral – directional damping
- Longitudinal short period damping
- Aerodynamic center of gravity limit
- Stall pattern indicator – cruise
- Stall pattern indicator – takeoff
- Stall pattern indicator – landing
- Cooper rating (no augmentation), lateral-directional
- Cooper rating (no augmentation), longitudinal
- Uninstalled thrust
- Temperature in flight
- Flotation
- Electric load (cruise, takeoff, climb, emergency)
- Hydraulic load (takeoff, approach)
- Turnaround time

*Examples are based on an aircraft system. Measurement of each parameter is to be accomplished based on specific operating conditions (e.g., altitude, weight, center of gravity, temperature, etc.).

(5) **Approach and method for obtaining current and planned parameter and accountable factor values. Data sources potentially useful in estimating these values include:**

   (a) **planned design changes, with projected effect of changes based on sensitivity relationships developed in Step E10. Examples of types of sensitivity relationships which can be applied to arrive at predicted parameter values are listed in Table 4-6.**

   (b) credible design analyses

   (c) simulation tests

   (d) Category I and II tests

   (e) historical learning curves appropriately adjusted

(6) Reporting form

Effectiveness Demonstration Planning

As previously indicated, a system FOM normally cannot in itself be physically demonstrated. The notion of effectiveness demonstration, of necessity, refers to a physical demonstration of the measurable performance parameters of a system, with the observable results analytically composited to arrive at a demonstrated FOM value. Demonstration planning during Definition, therefore, is to be responsive to this reality. It also is to incorporate a basic effectiveness demonstration approach which utilizes the standard Category I, II, III, and TAD tests planned for the system.

Effectiveness demonstration planning involves the following activities:

- Identification from the integrated test plan of those defined Category I, II, III, and TAD tests which can be considered to be system tests representative of the operational environment, and, therefore, suitable to be used for demonstration purposes
- Definition of the interrelation of demonstration tests which may be planned separately for programs of related specialty disciplines, such as reliability, safety, maintainability, human performance, etc., and the approach for their integration

TABLE 4-6 EXAMPLES OF SENSITIVITY RELATIONSHIPS FOR PREDICTED PERFORMANCE

- (X) change in takeoff maximum lift coefficient = (-y) feet takeoff distance
- (X) counts cruise drag = (-y) pounds payload
- (X) percent thrust specific fuel consumption = (-y) pounds payload
- (X) pounds liftoff weight = (+y) pounds payload
- (X) pounds liftoff weight = (+y) feet takeoff distance
- (X) pounds liftoff weight = (-y) feet per minute rate of climb
- (X) pounds liftoff weight = (-y) feet initial cruise altitude

- Definition of the approach for integrating Category III tests by the using commands and TAD tests
- Establishment of the approach for integrating compatibility tests conducted with augmenting systems
- Analysis of the tests planned for the evaluation of system performance to determine sufficiency of the planning for demonstration purposes. Also, analysis of the estimating problem associated with establishing confidence limits for FOMs and system parameters, including a description of the approach to be used. One such approach is the technique using Mellin transform and a Bayesian procedure to determine the output probability distributions for products of parameters with known input distributions. This technique is described in the RADC System/Cost Effectiveness Notebook.

Procedure

The procedure for the technical accomplishment of the effectiveness progress monitoring and demonstration planning activity can be summarized by the following general activities:

- Establish a basic effectiveness monitoring plan, including the approach for a TPM system
- Establish preliminary master list of system parameters and accountable factors which are to be tracked during Acquisition and Operational Phases. Correlate list with PBS elements
- Establish expected convergence profile for these parameters and accountable factors
- Establish monitoring points where effectiveness progress is to be formally assessed
- Identify the system parameters to be demonstrated, and the method by which the results are to be integrated to calculate a demonstrated FOM value
- Establish implementation guidelines, and identify data sources and methods for obtaining measures of current, predicted, and targeted values

- **Establish effectiveness status reporting format to include frequency of updating, approach to highlighting critical problem areas, and method for displaying the current and historical convergence progress of a parameter value to its target value for each critical item on the parameter list**

- Define an effectiveness demonstration plan to include suitable tests from the planned standard test programs which are to be used as demonstration tests. Analyze sufficiency of this test planning with respect to the number of tests scheduled and test balance of the critical system parameters to be demonstrated, and establish approach for determining confidence limit estimates.

Information Flow

The basic data required for the effectiveness progress monitoring and demonstration planning activity are:

- The parameters and accountable factors and their relative criticality composited in the effectiveness criticality matrix, the sensitivity relationships, and transfer functions from the effectiveness analysis updating activity. These data will provide the rationale for the formulation of the master parameter list, convergence profiles, and selection of system parameters to be demonstrated

- The specification performance values from the system performance specification and the detail major CEI specifications. These values were developed, allocated, and validated previously by the apportionment analysis activity

- Information from the system program management and schedule networks for establishment of formal reporting and review points

- Category I and II test plan, and the TAD and Category III test plan, if available

- Demonstration plans for the related specialty technical parameters, such as reliability, safety, maintainability, human performance, etc.

The outputs of this activity will:

- Provide the detail data requirements for effectiveness analyses to be accomplished during Acquisition
- Define the continuing effectiveness evaluations required during Acquisition
- Afford a perspective of the parameters with a high technical risk, and the rate of expected achievement of the target values for these and other parameters on a time basis
- Provide an analysis of the system test plan in terms of usability for current and demonstrated performance estimates
- Form a basis for performance incentive provisions.

Figure 4-5 summarizes the information network for the effectiveness progress monitoring and demonstration planning activity.

4.5 REPORT $\boxed{\text{Step E12}}$

General

A final report is to be submitted to the SPO summarizing the system and cost effectiveness formulation, evaluation, and assurance planning results for the Contract Definition Phase. The report will be used by system planners at HQ USAF, HQ AFSC, and the SPO, for many purposes including the following:

- To provide a basis for the synthesis of the best features of each contractor's design approach into an optimum system within the overall performance, cost, and schedule requirements and proprietary limitations
- To establish the traceability of design requirements, and to validate the sufficiency of performance requirements included in the system specification and the Part I detail specifications towards defining a system with optimum performance and cost effectiveness to meet mission objectives
- To establish the high technical and cost risk areas requiring focus and detail design and effectiveness analysis during Acquisition Phase

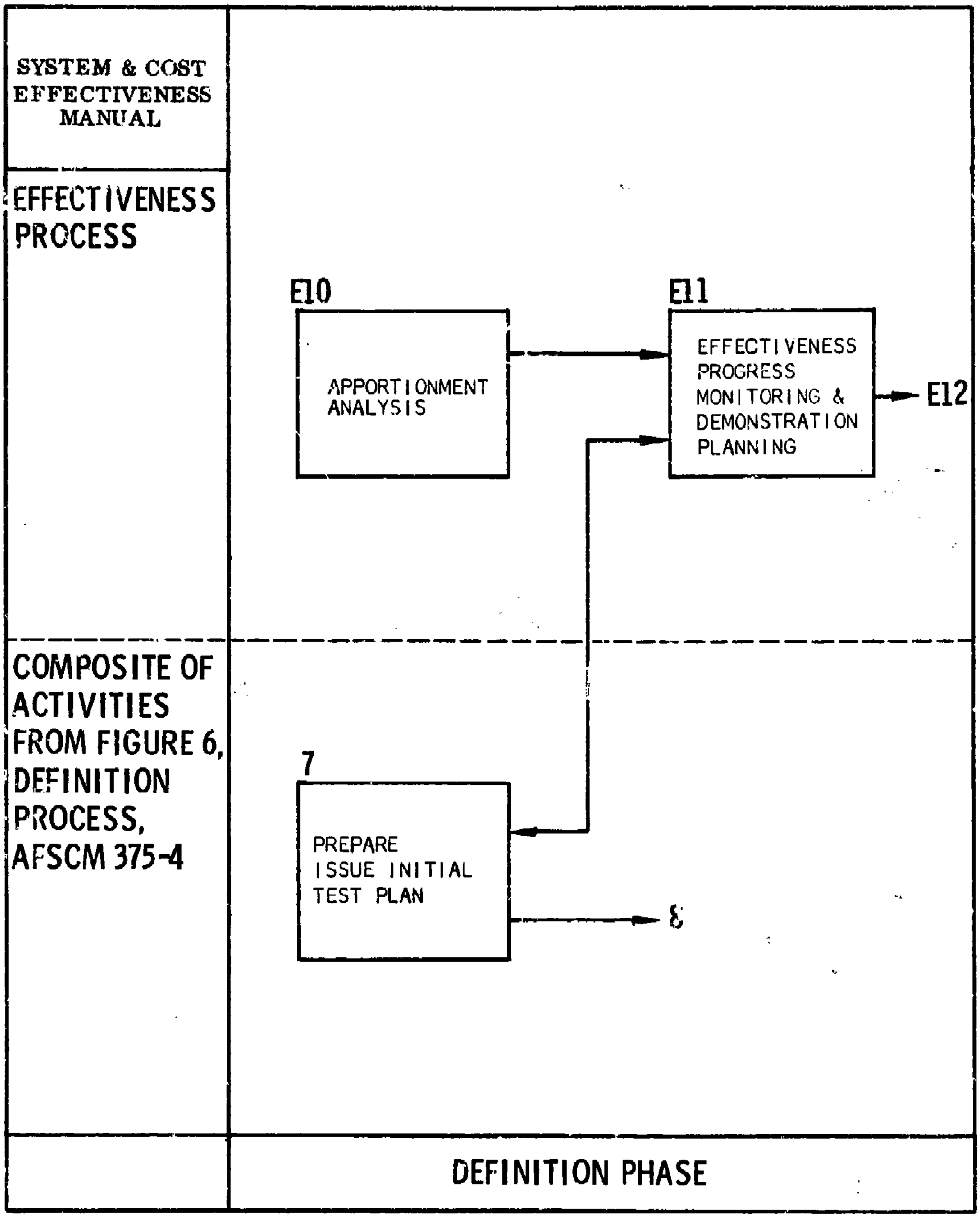


Figure	Effectiveness Progress Monitoring and Demonstration Planning Information Network	Page
4-5		4-42

- To have realistic data for updating of the TDP and for the preparation of the Proposed System Package Plan (PSPP), which signifies that the decision to proceed with Acquisition can be made
- To provide the reference framework and a continuum for the effectiveness activities to be implemented during Acquisition Phase

The system and cost effectiveness report is to include the following updated technical data:

- The mission analysis results, including descriptions of the specific objectives of the mission and mission threats anticipated by kinds, levels, and probability of occurrence
- Explicit definition of the principal FOMs, their technical traceability to specific system performance parameters composited, and quantitative values for each defined FOM and sub-FOM
- Expanded system performance requirements profile, including parameters taken into account and their assigned values
- Expanded system operational requirements profile, including parameters taken into account and their assigned values, maintenance concepts, logistics support concepts, personnel estimates by specialty skills, training concepts, transportation concepts, etc.
- Results of, and rationale for, effectiveness parameter selection, including criticality matrix
- Models and submodels used in the evaluation of FOM, sub-FOM, availability, dependability, capability, cost, and cost effectiveness measures, including explicit rationale and justification of analysis assumptions
- Major sensitivity relationships of each defined FOM to its critical accountable factors
- Transfer functions for the system level and subsystem level of functions in terms of output system parameters
- Descriptions of defined system states, state flow graphs as appropriate, and probability estimates for each defined state

- Tabulated analysis results of current estimates for FOMs, sub-FOMs, effectiveness parameters, and critical system parameters
- Data requirements and sources for Definition analyses accomplished and those contemplated for use in the Acquisition Phase
- Description of apportionment technique used and apportionment results on FOMs, sub-FOMs, effectiveness parameters, and critical system parameters
- Effectiveness progress monitoring and demonstration plan, including master list of parameters for TPM, expected convergence profile for these parameters, and demonstration test planning evaluation results.

Information Flow

All of the major activities, Steps E9 – E11, will provide inputs to the System and Cost Effectiveness Report for the Definition Phase. The technical data to be included in the report are directly usable for the preparation of the PSPP and other baseline documents needed to commence Acquisition. The basic information network for the report activity is shown in Figure 4-6.

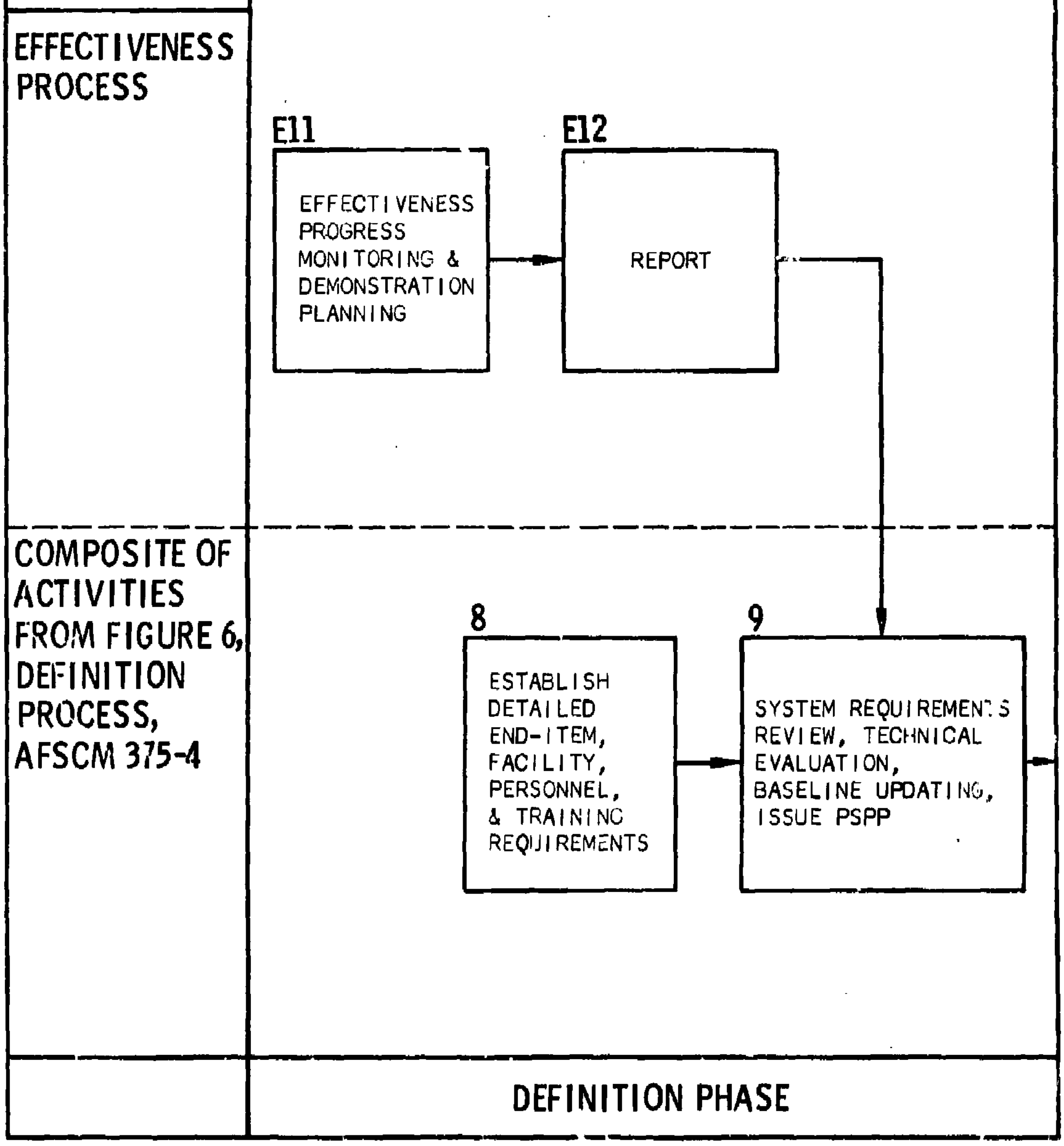


Figure 4-6 Report Information Network

Chapter 5

SYSTEM AND COST EFFECTIVENESS IMPLEMENTATION FOR ACQUISITION PHASE

Summary

The evolutionary system and cost effectiveness implementation process is continued into the Acquisition Phase to provide Air Force and contractor management with visibility and confidence of technical progress in meeting the defined effectiveness requirements and goals as system design natures. During this phase, the effectiveness process is addressed to the activities of (1) detail effectiveness analysis, (2) effectiveness progress monitoring and demonstration, and (3) final report. The detail effectiveness analysis activity provides a continuing, updated evaluation of the effectiveness impact from synthesis being accomplished on design solutions, and the extent that system performance will be responsive to the established effectiveness requirements and goals. The effectiveness progress monitoring and demonstration activity implements the plan defined during Definition. This activity provides the overview of technical progress on effectiveness growth, critical risk and problem areas, and achieved effectiveness performance at major milestone points, and employs a technical performance measurement system to achieve its purpose. The final report activity provides to the SPO a closing summary of the significant effectiveness progress achieved during the phase. The basic time-sequenced format used to describe the effectiveness activities of the Definition phase and their interactions with the system management procedures of AFSCM 375-4 on a composited basis is preserved for the description of the activities and procedures applicable to the Acquisition Phase.

5-1 GENERAL

The Acquisition Phase consists of two overlapping efforts of development and production. The phase starts with the issue of the System Program Directive and the preparation of the System Program Package (SPP). It ends with the acceptance of the last operating unit by the using command or organization, and when all changes required from Category II testing have been placed on contract. The fundamental purpose of this phase is to acquire and test the system elements required to satisfy the SPP and the system specification. The Acquisition Phase is intended to achieve the following objectives:

(a) Updating detail plans derived during the definition phase.

(b) Identification of spares required.

(c) Verification of Part I Detail Specifications and Inventory Equipment Requirement Detail Specifications.

(d) Accomplishment of preliminary and detail design, and performance of design reviews.

(e) Establishment of configuration of the system in terms of audited and approved Part II Detail Specifications.

(f) Beginning of production and construction.

(g) Preparation of procedural publications.

(h) Performance of Categories I and II and any follow-on development testing.

(i) Definition of logistic requirements in detail.

(j) Preparation for transition of system management from AFSC to AFLC.

(k) Preparation for turnover of the system to the using command or organization.

The technical activities of the effectiveness process to be implemented during this phase will contribute to the achievement of objectives (a), (b), (c), (d), (e), and (i).

Implementation of the system and cost effectiveness process during Acquisition is directed at the following basic purposes:

- To provide current and predicted estimates of system and cost effectiveness on a continuing basis as significant design details are developed on product configuration, or as performance requirements are changed.
- To provide a current assessment of technical progress in meeting requirements and goals on effectiveness-related parameters and measures.
- To provide the SPO with a compendium of the final effectiveness baseline used for analyses, the achieved versus required/targeted effectiveness, and the system improvement potentials for effectiveness growth.

The principal uses of the effectiveness process outputs are:

- To guide trade-off decisions.
- To establish system/subsystem traceability and validation of parameters affecting system and cost effectiveness.
- To evaluate current and predicted system and cost effectiveness status as design progresses to insure the evolution of a system that will meet the defined requirements and goals for an optimum cost, performance, and time balance.
- To reapportion effectiveness and system parameters as needed for optimum cost-performance-time balance.
- To provide management visibility of technical progress on effectiveness growth, critical problems, and high risk areas requiring timely attention through effectiveness analyses.
- To demonstrate effectiveness performance results under operational conditions.
- To determine whether effectiveness requirements and goals have been met.
- To assess the extent that operational tactics are affected by final effectiveness results.
- To validate areas requiring engineering modifications.

The system and cost effectiveness process during the Definition Phase was addressed to the definition of the effectiveness formulation, evaluation,and assurance baseline for the Acquisition Phase. Elements defined in detail include (1) effectiveness and effectiveness-related measures, (2) critical parameters and accountable factors influencing these measures, (3) sensitivities and relationships of the influences under operational conditions, and methods for their measurement, (4) achievable and firm performance requirements to be included into the system specification and Part I of detail specifications for optimum system effectiveness, (5) effectiveness analysis models, (6) data requirements for the analyses to be accomplished, and (7) progress monitoring and demonstration plan. Additionally, current estimates for the defined effectiveness measures were prepared to guide performance-cost-time tradeoff decisions, shape preliminary design solutions, focus the expected performance efficiency and economy of the defined system configuration, and highlight the technical and cost risk areas requiring special attention and resolution during system development.

The evolutionary system and cost effectiveness process is continued into the Acquisition Phase to provide an authoritative perspective of the technical progress towards meeting the defined effectiveness requirements and goals as design details are developed on product configuration. The activities required are summarized by the following implementation steps:

- $\boxed{\text{Step E13 - Detail Effectiveness Analysis}}$ This activity refines the analysis baseline. It includes (1) model changes, (2) parameter re-selection, (3) more precise definition of the FOM measures, operational conditions, and technical FOM traceability and representation, (4) reapportionment of effectiveness-sensitive parameters, (5) reassessment of data requirements, and (6) similar planning factors for valid analyses. Additionally, this activity provides a continuing series of effectiveness evaluations concomitant with the development of the product configuration.

- $\boxed{\text{Step E14 - Effectiveness Progress Monitoring and Demonstration}}$

  This activity provides management with the needed visibility of the technical progress on effectiveness growth, critical problems and continuing risk areas, and achieved effectiveness performance at major milestone points. This is accomplished with a dynamic technical performance measurement program and through use of selected test results.

- $\boxed{\text{Step E15 - Final Report}}$ This activity provides a report that summarizes the significant results of the effectiveness formulation, evaluation, and assurance activities implemented during the Acquisition Phase, including (1) the updated baseline used for analyses, (2) comparison of the final measured, projected, and demonstrated effectiveness values, (3) an analysis of the operational implications of the results, and (4) system improvement potentials for future effectiveness growth.

System effectiveness requirements and targets normally will be specified in the SOW, the system specification, and Part I of detail specifications. Typical requirements for inclusion in these documents for execution by the selected integrating and associate contractors are:

- Updating of effectiveness analysis baseline, specifically to include re-evaluation of effectiveness parameter selection, the effects of parameter requirement changes on the effectiveness FOM, and modifications to models provided or approved by the procuring activity.
- Refinement on a continuing basis of system and cost effectiveness analyses, including availability, dependability, and capability analyses, with the analysis results to be made available for review by the procuring activity at specified development and production milestones, such as PDR, CDR, FACI, Category II testing, and Technical Approval Demonstrations (TADs).
- Preparation of computerized analysis routines to a specified computer language and format as applicable.

- Control of effectiveness model changes affecting configuration-effectiveness relationship as Class 1 changes subject to the change control procedures of AFSCM 375-1.
- Coordination of guides and standards for the accomplishment of subcontractor analyses.
- Updating and implementation of a dynamic effectiveness progress monitoring and statusing program, to include a technical performance measurement system and a systematic procedure for isolating design changes with major effectiveness implications.
- Updating and implementation of an effectiveness demonstration plan.
- Final reporting of analysis results.

The effectiveness process to be implemented during the Acquisition Phase is compatible with, interacts, and supports both the system program management and systems engineering management procedures as defined in AFSCM 375-4 and 375-5, respectively. The three processes have complementary activities for translating detail design requirements into optimum performance-cost-time solutions within sensible risk allowances. An overview of the relationships and interactions was provided in Figure 2-3 in Chapter 2.

5-2 DETAIL EFFECTIVENESS ANALYSIS Step E13

General

The principal product of the Acquisition Phase is the acceptance of a total system which is capable of performing the intended mission in the operational environment. The phase begins with the PSPP revised to reflect any changes required by the System Program Directive and converted into the System Package Program (SPP), the master plan for this phase. Preliminary detail design is then initiated by the Acquisition contractor. This preliminary design is to assure that the design approach selected is acceptable to satisfy the specified requirements of the SOW, the system specification, Part I of detail specifications, and other baseline documents. Subsequently, engineering

definition continues throughout this phase until the system has been described by Part II detail specifications and drawings. As additional detailed design information becomes available, such as from test results, changes to existing requirements may be required.

The detail effectiveness analysis activity is addressed to a companion and continuing definition and critical evaluation of the impact to effectiveness of the synthesis being accomplished on alternate design solutions, and the extent that the detail design being developed will be capable of meeting the established system effectiveness requirements and goals. Effectiveness definition and analysis results requiring continuous updating and refinement include the following activities initiated during Concept Formulation and/or Definition:

- Mission analysis
- Principal FOM and sub-FOM technical traceability and correspondence to functional, specialty, and operational parameters
- Performance requirements analysis
- Operational requirements analysis
- Effectiveness parameter selection
- Model and sub-model structuring
- System and cost effectiveness analysis
- Apportionment analysis
- Progress monitoring and demonstration planning

Mission Analysis

The refinement of the mission analysis is addressed primarily to improving the definition of the specific objectives for the mission by:

- Incorporation of latest intelligence information on the kind, magnitude, level, and probability of enemy threats expected to be present at the time of initial operational deployment, and at a time five years in the future.

- A more accurate quantitative definition of the terminal performance parameters to be achieved by the system as evidence that the specific mission objectives are met, including the specification of a minimum, maximum, or range of required or targeted values for the parameters.
- A more precise definition based on design details being developed of the system neutralizing capabilities and limitations to counteract enemy threats, including the capabilities of augmenting systems which may be planned for simultaneous employment in the mission, avoidance tactics to take advantage of special system characteristics, and other countermeasures. Analytical techniques, such as computer simulations, can be used to obtain a penetrability and/or vulnerability profile as a probability function of time, threat levels, angle of attack, altitude, and similar dependent variables.

Principal FOMs

The values for FOM measures defined at the conclusion of Definition are not expected to change for the Acquisition Phase. However, a more precise definition is required of the specific system parameters composited by the effectiveness parameters of availability, dependability, and capability that critically influence each FOM measure, and the technical logic by which each FOM relates to these system parameters and their sets of critical accountable factors. A similar refinement in definition will be needed for each sub-FOM developed.

Performance Requirements Analysis

First-level system functions previously defined normally will not change during Acquisition. Second-level, subsystem functions, however, may change as a result of trade-off studies to investigate alternate means of accomplishing the tasks, consistent with the product configuration being developed and resource restrictions. A refinement of the time-based, operational requirements profile will be required to include the definition of (1) specific first and second-level functions influencing

effectiveness, (2) the set of corresponding system and subsystem parameters that can be measured as evidence of successful accomplishment of these functions, (3) quantitative values and tolerances for the parameters, and (4) the natural environmental spectrum associated with each function.

Operational Requirements Analysis

A corresponding updating and refinement of the system operational requirements profile (and as necessary, the system and CEI specifications) are accomplished based on detail data developed from the following systems engineering activities:

- Trade-off studies of maintenance, test, and activation factors to determine detail requirements imposed by the AVE or OGE, MGE, and AAE selected during Definition. Factors to be analyzed include (1) levels of maintenance, (2) quantity of equipment, (3) estimated range and depth of required spares and spare parts, (4) facility utilization, (5) test and activation equipment, and (6) total predicted costs, all of which will influence operational parameters defined in terms of measures such as downtime, costs, and in-commission rates.
- Development of detail maintenance functions and design requirements for maintenance functions, maintenance end items, facilities, and maintenance personnel and training.
- Cost-effectiveness trade-off studies on maintenance loading to establish the combination of equipment, spares, and personnel required to maintain the system efficiently and economically. Accountable factors, such as the number of days deployed before a unit is returned for preventive maintenance, the number of units to be deployed concurrently, the hours of work per maintenance personnel, and equipment availability, are assessed as a part of these studies.
- Detail studies of transportation time, costs, and relevant factors.
- Detail studies of intersystem interfaces, such as combined reaction time, error contributions, survival time, and target identification time.

- Studies of special facilities required for achieving a required readiness state for the system.
- Detail identification of the natural environmental spectrum expected to be influential on the operational parameters.

Effectiveness Parameter Selection

Refinements for the effectiveness parameter selection activity is a continuous process during Acquisition and is addressed to:

- A re-evaluation for criticality, and a reselection as necessary, of the output parameters for the previously defined system and subsystems and of the accountable factors for subsystems with defined sub-FOMs.
- A revision of the transfer functions to obtain a more detailed and accurate representation of the input-output relationships for the system and subsystem functions.
- A further extension of the transfer functions to lower design levels to accommodate product configuration trade-off analyses for arriving at the required inputs for the critical accountable factors.
- A revision of sensitivity functions based on detailed analytical studies and test results.
- A revision of the normalized sensitivity coefficients included in the criticality matrix based on detail analysis and test results.

Model Structuring

The system and cost effectiveness submodels will change as a result of any system performance parameter reselections. Additionally, other model changes will be required on a continuous basis to insure an accurate measure of mission objective accomplishment in terms of measurable system performance parameters. Typically, the following refinements will be needed:

- Continuous re-examination, verification, and modification of assumptions, and reduction of other analytical error sources to increase model precision based upon current design details, more penetrating analytical studies, and test results.

- Validation and expansion of the defined system states, and further definition of the state progression logic. Table 5-1 shows a typical progression logic for establishing, expanding, and defining system states during Acquisition, and the evolution linkups of these states to those defined in earlier phases. For most applications, the system operating conditions that can influence effectiveness are reducible to three conditions. These are the conditions of fully operable, fail-operable (partially operable), and inoperable. Of these three conditions, only the fail-operable condition should be divided into different system states. From the viewpoint of evaluating the effect of different system states on an FOM measure (and hence, on the fulfillment of one or more mission objectives), there is no practical reason for dividing the fully operable or inoperable system condition into different system states. A rationale for establishing the different divisions of state groups to be associated with the fail-operable condition is to define as belonging to the same state group all system anomalies resulting in the same order of magnitude of change to an FOM value (e.g., ±.05). For most applications, the number of divisions should not exceed five groups of significantly different states. This is concordant with the premise that a larger number of state groups would be analytically unwieldy. It would also be incongrous with the errors inherently present in approximations to transfer functions and in estimates of initial and transition probabilities for the defined states. Such errors would not be reduced significantly by a finer division of state groups. A procedure for establishing the different states to apply to the fail-operable system condition is as follows:

  (a) Identify the major sub-functions for each top-level system function.

  (b) Determine the output distribution for each system parameter associated with the previously identified top-level system function by evaluating the significant combinations of fail-operable anomalies which can arise with the sub-functions (e.g., simultaneously, one

TABLE 5-1 STATE PROGRESSION LOGIC

Mission Operating Condition	Conceptual Phase System Operating Condition	Conceptual Phase System State**	Definition Phase System Operating Condition	Definition Phase System State**	Acquisition Phase System Operating Condition	Acquisition Phase System State**
• Non-abort	Fully operable	1.0	Fully operable	1.0	Fully operable	1.0
			Fail-operable*	1.1	Fail-operable*	1.1.1 1.1.2 etc.
• Abort	Inoperable	2.0	Inoperable	2.0	Inoperable	2.0

* May be denoted as "partially operable."

** States can be renumbered (e.g., 1, 2, 3, . . .). An example of State 1.1.1 is "one out of four engines not operating." This state may be renumbered as State No. 2; State 1.1.2 could be defined as "two out of four engines not operating, one on each side" and renumbered as State No. 3; etc.

sub-function inoperable, a second sub-function operable but out of tolerance, and all other sub-functions in tolerance). Relate a system parameter output value for each such combination. Use simulation or direct calculations from the mathematical transfer functions to determine these output values.

(c) Calculate an FOM estimate for each output value. Categorize the analyzed combinations of sub-function anomalies into practical broad-range state groups based on the FOM values thus determined.

- Updating the estimates for the probabilities of the system being in a specific initial state and making a transition from state to state. With the important failure combinations previously identified and categorized into distinct state groups, and with results from breadboard/development tests properly translated, current estimates can be validly obtained.
- Further definition of the effectiveness evaluation baseline, including a restructuring as needed of the threat level groupings to reflect the latest threat posture identified in the updated mission analysis.
- Revision of the system effectiveness submodels. The submodels defined for the effectiveness parameters of availability, dependability, and capability will require updating to reflect the impact of new performance requirements or parameter reselections. Separate models used to evaluate the critical system functional, specialty, and operational parameters composited by the effectiveness parameters also will require updating as the design details evolve, and as the critical accountable factors and their values are more accurately defined.

- Inclusion of a new system parameter, the quality parameter, to represent the influence on the FOMs of variations from the established product configuration during production. The quality parameter will moderate the level of system availability, dependability, and capability achievable. Typically, the quality parameter can be considered to act as an accountable factor for each of these effectiveness parameters. It can be defined as the probability of detecting a defect critically influencing system performance when such a defect is present, and is a function of factors such as (1) the probability of a set of critical defects occurring, (2) the probability of detecting these defects when they are present, (3) the sensitivity of the effectiveness parameters to the presence of these defects when they escape detection, and (4) the measurability and frequency (opportunity) of measurement for the defined defects.

- Expansion of the cost submodels and cost relationships defined for each major category of cost. This will provide increased precision and realism to the system cost model and will allow detail cost trade-offs to be validly accomplished on high technical and cost risk product areas.

- Formulation of cost effectiveness submodels that are compatible with the system cost effectiveness models. These submodels are to be used for assessment of the major performance-cost-time trade-off alternatives on product configurations at the subsystem and lower levels.

- Re-evaluation of the data requirements and sources needed as model inputs to obtain valid output estimates of FOMs, effectiveness parameters, system parameters, and cost effectiveness measures defined for the system and subsystems. Sources of data expected to be of major usefulness include engineering analytical studies, preliminary and critical design reviews, first article configuration inspections (FACIs), CEI and system/facility acceptance tests, system Category I and II tests, technical approval demonstration tests (TADs), and the operational phase Category III tests.

System and Cost Effectiveness Analysis

System and cost effectiveness analyses will be required on a continuous basis during Acquisition. Principally, the analyses are addressed to:

- Refining the optimization of critical system parameters and accountable factors to shape design solutions for high risk areas, to validate changes to performance requirements in the system specification and to detail CEI specifications based on their integrated effects on other design criteria, also to establish detail product design requirements.
- Validating changes to the original scope of technical programs, such as the reliability and maintainability efforts.
- Justifying engineering change proposals on the basis of net effect to the overall capability and economy of the system.
- Developing information needed for the system preliminary design reviews, (conducted on an incremental and integrated basis early in Acquisition) to assess the performance effectiveness, economy, and feasibility of the design approach.
- Establishing from trade-off studies the cost-effective detail requirements for maintenance elements of the system. These elements include detail maintenance functions and design requirements, maintenance personnel and training, and maintenance facilities. Typical trade-off studies to optimize these maintenance elements should include the factors of maintenance levels, equipment quantities, range and depth of required spares and spare parts, facility utilization, test and activation equipment, and costs.
- Updating of sensitivity functions and the criticality coefficients to improve their accuracy for use as practical design guidelines and to provide detail design visibility of the influence that changes to design requirements for critical accountable factors will have on the system parameters and FOMs.

- Providing current and predicted estimates for the system and subsystem FOM measures, effectiveness parameters, and critical system parameters. Current estimates can be prepared from the results of engineering analyses, Category I tests/verifications (especially those performed on the complete system or on broad assemblages of CEIs and subsystems), and extrapolations of historical data available from Government data banks, contractor sources, or standard sources (e.g., MIL-HDBK 217 data appropriately adjusted). Predicted estimates of the expected convergence values for these measures and parameters can be made based on performance requirement changes or additional design refinements anticipated to be incorporated prior to first delivery of the completely developed system. Current and predicted values for the system FOMs and parameters are to be prepared when a major design change occurs, when significant test and evaluation results are obtained, and to support system design reviews, FACI, acceptance tests, and TADs.
- Developing information to support critical design reviews (CDRs). This information is to include the system and cost effectiveness rationale and traceability for the established detail design and performance requirements.
- Providing current and predicted estimates of cost effectiveness measures concurrently with the FOM and parameter estimates to assess the performance-cost-time balance of the design being evolved.
- Providing confidence limits for each FOM and cost effectiveness estimate to reflect the precision of the estimates.

Apportionment Analysis

The branching of the apportionment process below the second-level (subsystem) accountable factors will be required during Acquisition to provide the technical traceability of design and performance requirements appearing in major CEI detail specifications and product specifications. The apportionment rationale and techniques described for this activity during the definition phase are equally applicable for this extension of the apportionment process.

A reapportionment of the values allocated during Contract Definition to subsystem parameters, FOMs (sub-FOMs), and accountable factors will be required if new subsystem constraints are surfaced (from development studies) which are neither cost-effective nor technically feasible to overcome. A readjustment, therefore, of the previously allocated subsystem design criteria must necessarily be made based on more refined trade-off studies to arrive at realistic and firmly achievable subsystem design requirements.

Additionally, top-level system parameters composited by the effectiveness parameter sets of availability, dependability, and capability may require cross-reapportionment. The need for a reapportionment among these system parameter values at this point in time may arise from extreme circumstances, such as new intelligence information of enemy potentials influencing system performance capability.

Progress Monitoring and Demonstration Planning

Prior to the implementation of the effectiveness progress monitoring plan defined during Definition, the master list of parameters and accountable factors to be tracked during development, and their expected convergence profile, are to be refined and validated. This is to insure that only effectiveness-critical performance requirements, including high technical and cost risk areas, are selected for inclusion in the Technical Performance Measurement (TPM) system. Alterations to the master list and profiles may occur as a result of refinements, such as reapportioned and/or additional performance requirements, re-ordering of the sensitivity rankings in the criticality matrix, and revised learning curves based on a better defined design solution. Additionally, the format for reporting of status on the current, planned (anticipated), and demonstrated parameter values achieved and assigned, including the approach, methods, and data sources to be used for arriving at current and predicted estimates, are to be re-examined and updated.

Similarly, the effectiveness demonstration plan, which is based on demonstrating the extent to which measurable and critical system parameters are met, is to be updated. This updated plan is to reflect the contractor plans for Categories I and II testing, to incorporate the latest Category III operational demonstration test planning by the using command or agency, and to be responsive to the TADs planned for the system in the operational environment as a part of the turnover of the system to the using command or agency. The analysis of the sufficiency of the tests for demonstrating system effectiveness and the method by which demonstration test programs for related efforts will be integrated (e.g., reliability and maintainability tests) are to be revised based on the latest test planning information.

Information Flow

The basic data required for the detail effectiveness analysis activity are available from regular development sources. Most of these sources are progressively updated during Acquisition. Principal sources include the following:

- SPP and the updated program and design requirements baselines.
- Definition Phase system/cost effectiveness report.
- Program work breakdown and contractor work breakdown structures.
- Detail design data.
- System test plan.
- Results of Category I tests and evaluations.
- Updated engineering analyses, RASs, engineering trade-off studies to establish detail solution approaches, schematic diagrams, time lines, maintenance analyses, and the system operational plan.

The outputs of this activity will contribute to:

- The updating and validation of the system specification and Parts I and II of the detail specifications for major CEIs.
- The assessment of the effectiveness influence due to intersystem and intra-system interfaces.
- The creation of design solutions that are optimumly balanced for performance, cost, and time factors.
- The timely focusing of development effort onto high technical and cost risk areas impacting system and cost effectiveness.
- The technical base for conducting the effectiveness progress monitoring and demonstration program.
- An integrated perspective of overall system performance capabilities to support program elements, such as program reviews, requirements reviews, design reviews, and engineering change requests.
- A basis for better and more timely system management and systems engineering management decisions.

A summary of the basic information network for the detail effectiveness analysis activity is shown in Figure 5-1.

5-3 EFFECTIVENESS PROGRESS MONITORING AND DEMONSTRATION Step E14

General

This activity implements the effectiveness monitoring and demonstration plan defined during Definition and updated early in Acquisition. The activity places emphasis on providing Air Force and contractor management with visibility and confidence of the current, predicted, and proven program performance achievements. Regular outputs of the activity will provide guidance for valid and timely decisions by project managers addressing the integration of the multiple functional, specialty, and operational performance parameters, and their associated technical disciplines, in support of overall program goals.

This activity is primarily directed at the preparation and issue of timely status reports reflecting the achieved and anticipated effectiveness progress during Acquisition. The technical performance history from the inception of Acquisition, including measurements of current, planned (anticipated), and demonstrated values of FOMs, effective ness parameters, and system parameters, are to be provided to the SPO on a continuing basis. This information provides the insight into the rate at which design solutions are converging onto the critical performance requirements or allocated values on a time basis, and those high risk areas and technical variances from targets where major effort should be concentrated or redirected. To provide an overview of the convergence progress for each measure, summary charts can be used. An example of such a chart is a parameter convergence profile (planned value profile) chart as shown in Figure 5-2.

Estimates of current and planned values are to be based on analytical, test, and evaluation data, including:

- Credible engineering analyses
- Simulation studies
- Category I and II tests, FACIs, and system/CEI acceptance tests
- Historical projections, including learning rate

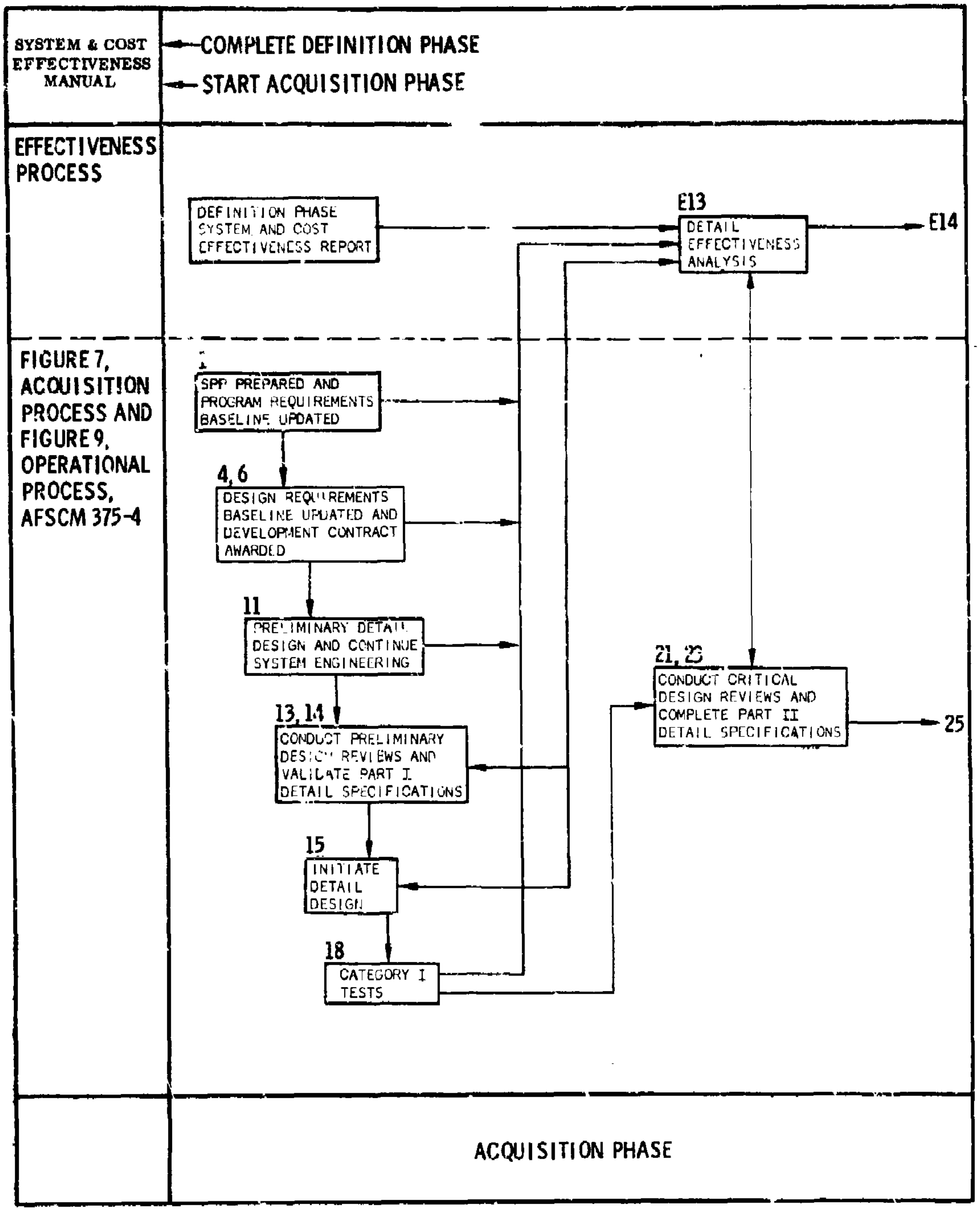


Figure 5-1	Detail Effectiveness Analysis Information Network	Page 5-20

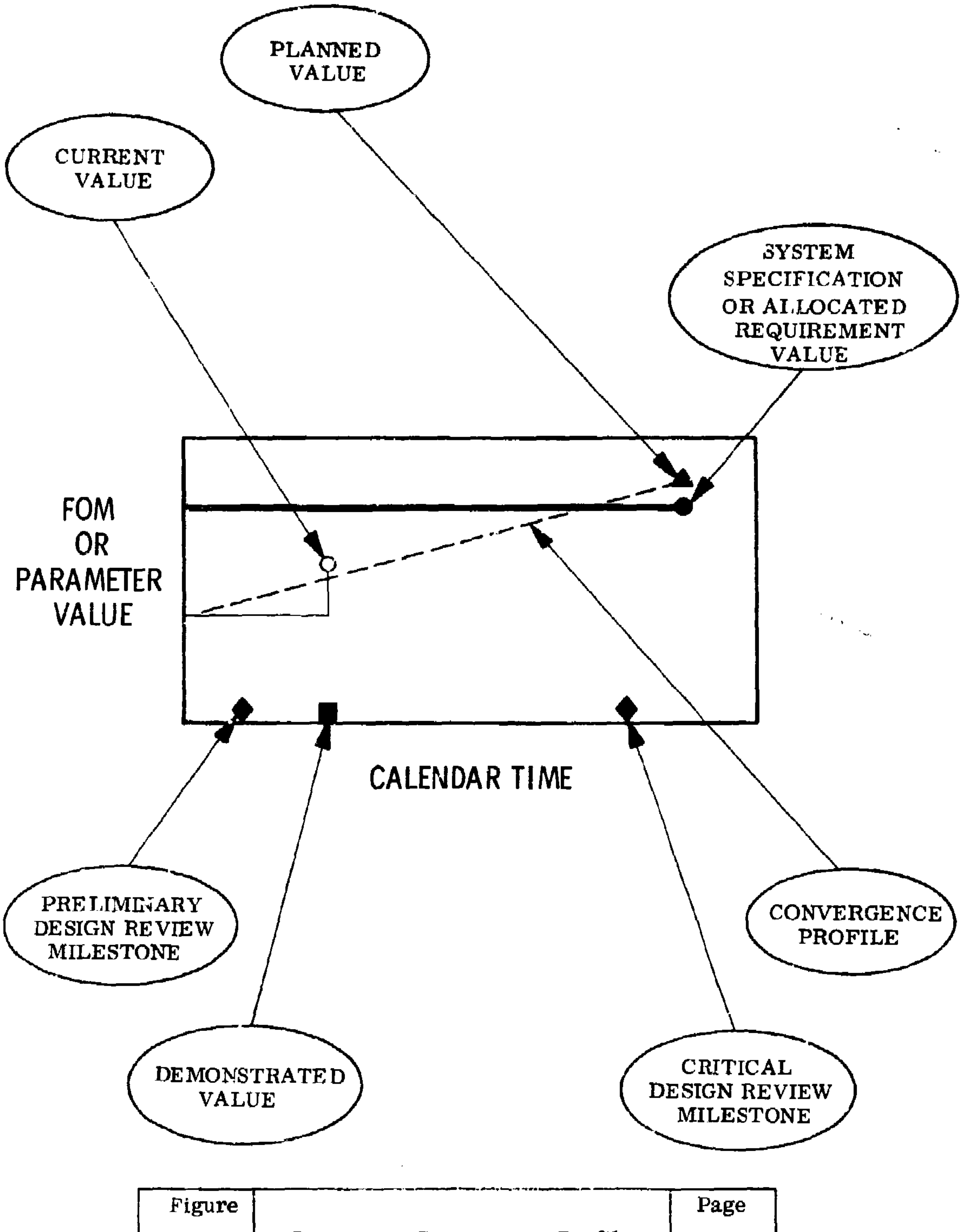


Figure 5-2	Parameter Convergence Profile	Page 5-21

Demonstrated values are to reflect the results from integrated performance tests in the actual environment. Test results that are to be used to determine demonstrated performance include those from Category I, II, III, and TAD system tests which are normally planned as a part of the overall Acquisition and Operational programs.

Information Flow

The effectiveness monitoring and demonstration status report will provide the SPO and contractor management with summary-level effectiveness data that will be useful for the following purposes:

- Guide technical evaluations of program progress
- Guide program redirection
- Highlight problem areas as they occur for corrective action
- Document design solution history and effectiveness growth
- Validate engineering design changes and modifications
- Guide deployment tactics changes

Figure 5-3 summarizes the information network for the effectiveness progress monitoring and demonstration activity.

5-4 FINAL REPORT $\boxed{\text{Step E15}}$

General

A final report is to be submitted by the Acquisition contractor to the SPO for review and acceptance. The submittal of the report is to be coincident with the delivery of the last system to the using command or agency, signifying the end of the Acquisition Phase. The final report is to indicate:

- The final analysis baseline used for the effectiveness evaluations, including the final form of all models, the explicit description of assumptions and analysis conditions that apply to their use, and levels of threats.

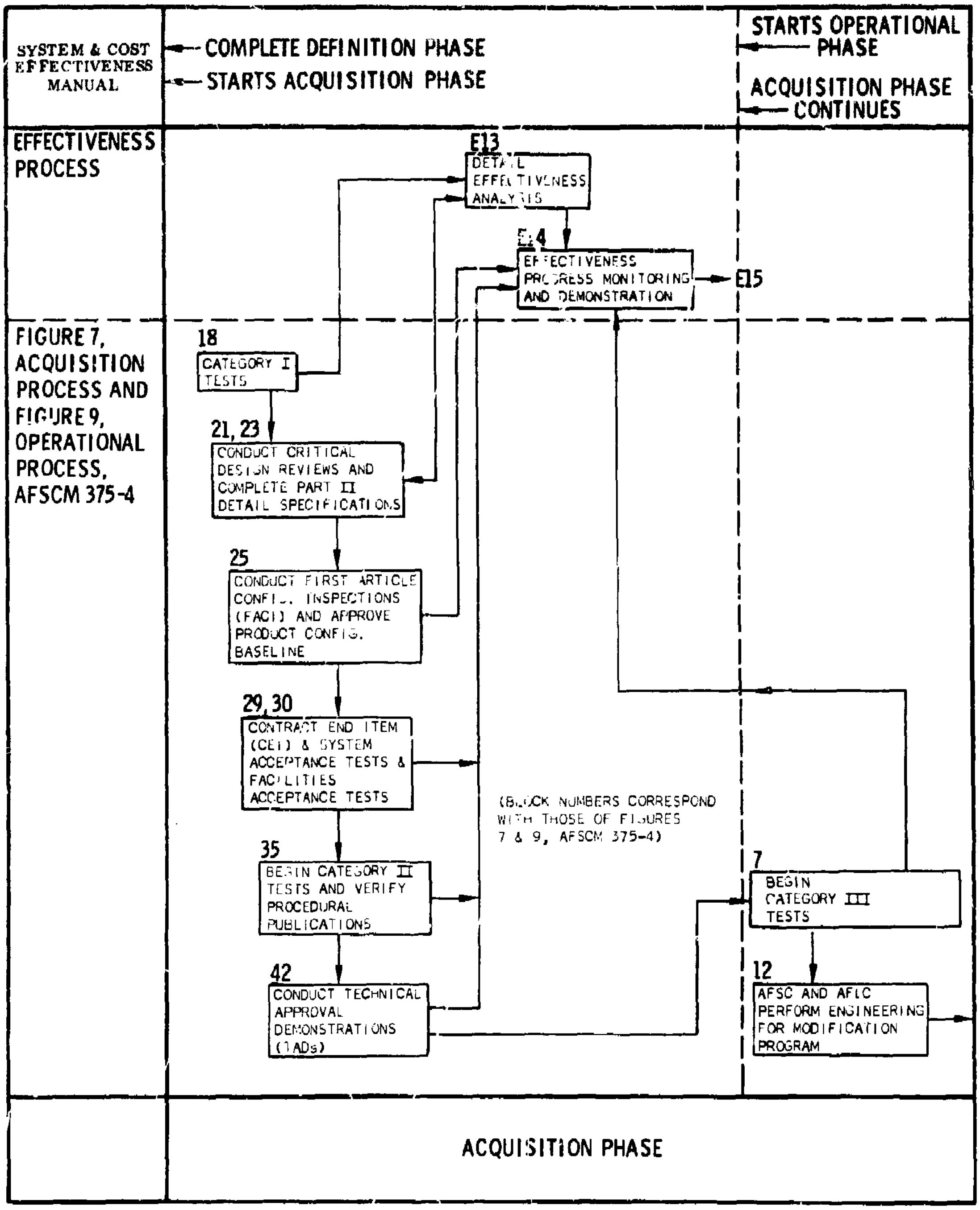


Figure	Effectiveness Progress Monitoring and Demonstration Information Network	Page
5-3		5-23

- The final estimates of current, planned, and demonstrated values versus specification requirements or goals for the system and subsystem FOMs, the effectiveness parameters, and the critical system parameters composited by the FOMs.
- Recommendations for model and estimate improvements based on factors such as model sensitivity to specific assumptions, more precise representation of the technical link-up of FOMs to system parameters and accountable factors, and performance areas imcompletely demonstrated.
- Identification of system constraints and improvement potentials for future effectiveness growth.
- Analysis of the operational implications of the achieved effectiveness.

<u>Information Flow</u>

The basic inputs for the contractor final report is the effectiveness progress monitoring and demonstration status report, augmented by specific, detail effectiveness analysis reports and studies documented by the contractor throughout the Acquisition Phase. Upon acceptance, the final report submitted by the contractor can be merged by the SPO into the final system report submitted to higher headquarters describing total system accomplishments during Acquisition.

Chapter 6
SYSTEM AND COST EFFECTIVENESS TECHNICAL MANAGEMENT

Summary

Significant Air Force and contractor participating management actions are necessary to insure the effective attainment of the objectives associated with the implementation of the system and cost effectiveness management process. The significant actions which are primarily the responsibility of Air Force management are (1) determining and specifying Figures of Merit, (2) establishing and specifying the data needed to document and to provide continuing visibility and confidence of overall system progress towards meeting technical goals and requirements, and (3) specifying required technical analyses for credible and defensible effectiveness evaluations. Major actions which are principally the responsibility of contractor management are (1) implementing the effectiveness process, (2) planning for data to provide for their maximum utility in effectiveness evaluations, and (3) organizing for management of the effectiveness effort. For both sets of actions, fundamental considerations and guidelines are delineated.

6-1 GENERAL

The principal objectives of the system and cost effectiveness management process are to provide Air Force and contractor management with:

- A continuing visibility and quantitative measure of confidence in overall system progress towards meeting technical requirements and goals.
- A formalized rationale for better and more timely program and technical decisions.
- Assurance that the system as conceived, defined, developed, produced, and transferred to the using command or agency possesses an optimum balance of performance capability and cost.

The effective attainment of the objectives is a participating Air Force and contractor management effort requiring strong discipline and an orderly approach. Significant management actions necessary for an efficient and effective implementation of the system and cost effectiveness process involves:

Air Force Management Action

- The proper determination and specification of Figures of Merit that will provide an accurate and valid measure of the expected system performance response to meet assigned mission roles.
- The establishment and specification of the type and amount of data needed, appropriate to the system type being procured,to support program decisions and to provide visibility and confidence of system and cost effectiveness achievements and progress.
- The specifying of the particular technical analyses required for an accurate evaluation of system and cost effectiveness based upon identifiable needs for the analyses.

Contractor Management Action

- The efficient implementation of the system and cost effectiveness management process with its continuum of activities.
- The scientific planning for the acquisition of realistically attainable and valid data necessary for conducting effectiveness analyses.
- The establishment and implementation of organization, management, and data feedback plans and controls for the effectiveness activities.

The system and cost effectiveness management implementation process has broad applicability to most Air Force systems and procurement situations. For any application, however, special management attention must be given to the need for selectively applying the technical elements and procedures of the process. This is to acknowledge the special program considerations concomitant with the specific nature of a system or project, such as the type of contract, the program complexities, and the absence of formalized program phases with their concentration of effort.

6-2 AIR FORCE MANAGEMENT

Determining and Specifying Figures of Merit

The proper determination and specification of system Figures of Merit are described in paragraphs 3-3, 4-2, and 5-2 of the manual. This task is characterized by a succinct translation of each set of mission objectives into a quantitative measure of overall system performance. A precise statement of the specific mission demands against which the system is being acquired is a fundamental consideration in specifying Figures of Merit that are meaningful, realistic, and accurate. These mission objectives must be defined in terms of measurable, system performance, behavior, and characteristics. A system is normally a part of an overall military force structure. To achieve precision in the definition of the mission objectives for a system, the system objectives must be traceable to top-level system effectiveness goals of the force structure (or still higher levels if overall Air Force, Department of Defense, or national objectives are being addressed). Branching from the force structure level is a layered hierarchy of mission requirements with specific system effectiveness goals assignable for each operational level down to the system level. Logically, this hierarchy can be considered as a Figure of Merit (effectiveness) tree or breakdown structure. The focal point of the Figure of Merit tree normally will be the mission objectives assigned to the force to be deployed in a specific time frame to interdict, deter, or otherwise control a threat to national security. A Figure of Merit can be established for each set of significantly different mission objectives for the force structure by conducting force-level studies addressing the required system mix of the force appropriate to the threat environments envisioned. These studies should consider factors such as intelligence estimates of enemy offensive and defensive potentials, and the Air Force strategies and tactics to be employed to counter the threat potentials based on the technical possibilities of developing the needed force composition. Upon identification of the required force composition and effectiveness, the assignable set of specific mission objectives and Figures of Merit for each of the different systems in the force can be resolved from the higher order force objectives and Figures of Merit. As an added degree of detail for apportionment and other analysis, a simultaneous breakdown of the Figure of Merit parameters of availability, dependability, and capability can be accomplished along with the cascading of the Figures of Merit from a top force structure, or any intervening level, down to the system level. Figure 6-1

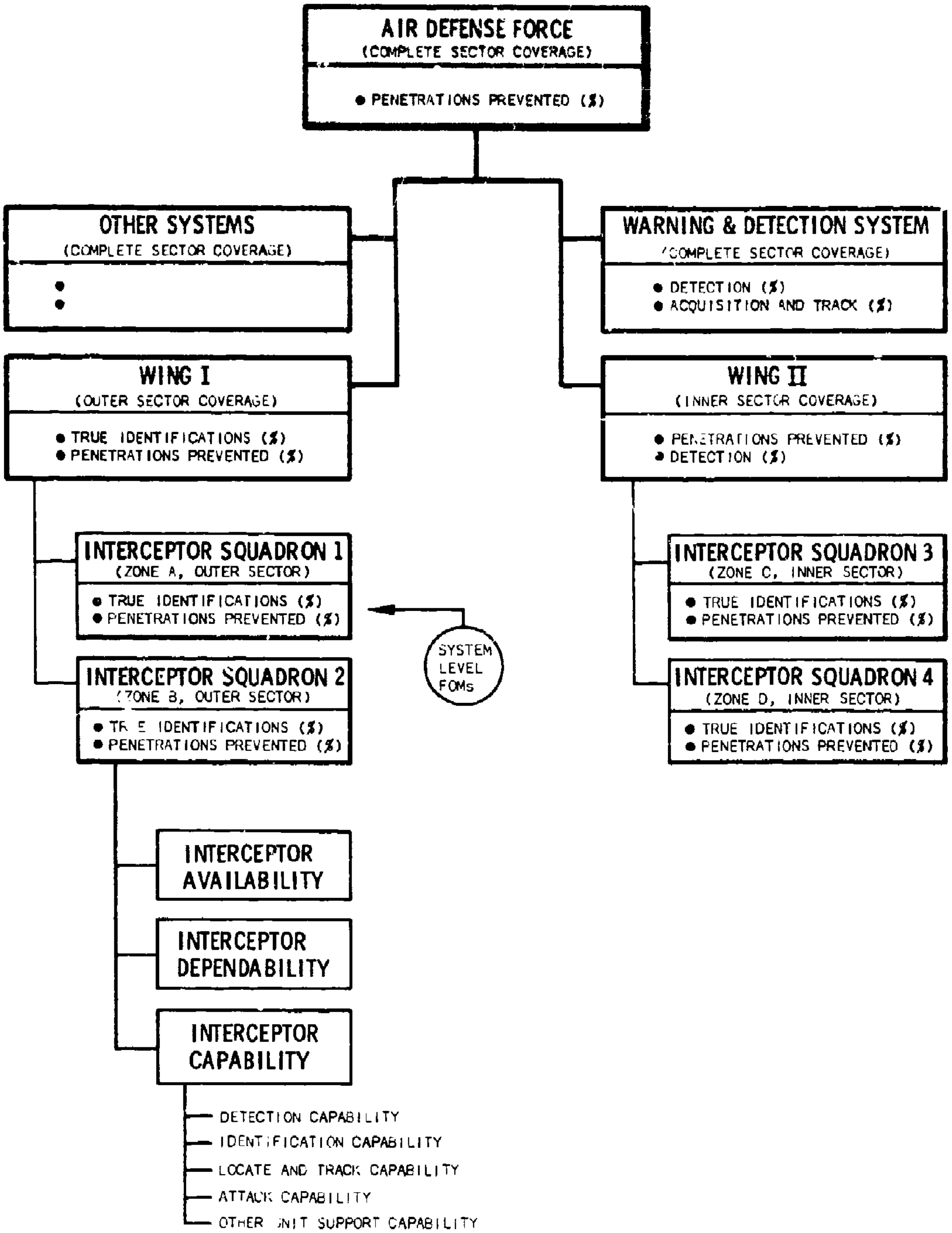


Figure		Page
6-1	Figure of Merit Tree	6-4

illustrates a Figure of Merit tree for a hypothetical continental Air Defense Force consisting principally of a warning and detection system and two interceptor aircraft wings. The force is assigned to cover a sector area. This area is partitioned into two smaller areas, the outer sector area and inner sector area, with each of the two areas further divided into two zones. The Figure of Merit tree shows the downward branching of the Figure of Merit for the Air Defense Force to the interceptor system Figures of Merit.

Establishing and Specifying Data

Factors to be considered in establishing and specifying the data required to document the program effectiveness analyses and to provide the continuing visibility and confidence of system and cost effectiveness achievements and progress include:

- The data output need and form. The data must be in a form usable to support program decisions.
- The data output quality. A confidence must exist that the data will be valid, accurate, and defensible to support program decisions.
- The level of data detail. The data level should be limited to the major CEI level, or higher levels to which all items of deliverable hardware are identified.

As a minimum, the following data items should be specified:

- The system and cost effectiveness report for Concept Formulation. This report is described in paragraph 3-9 of Chapter 3.
- The system and cost effectiveness report for Definition. This report is described in paragraph 4-5 of Chapter 4.
- An effectiveness progress status report to coincide with the system PDR, FACI, CDR, acceptance test, Category II test, and TAD milestone points. This continuing report is described in paragraphs 4-4 and 5-3 of Chapters 4 and 5, respectively.
- The final system and cost effectiveness report for Acquisition. This report is described in paragraph 5-4 of Chapter 5.

Specifying Required Analysis

The technical analyses required for a credible evaluation of system and cost effectiveness performance are:

- Mission analysis (paragraphs 3-2, 4-2, and 5-2)
- Figure of Merit definition analysis (paragraphs 3-3, 4-2, and 5-2)
- Performance requirements analysis (paragraphs 3-4, 4-2, and 5-2)
- Operational requirements analysis (paragraphs 3-5, 4-2, and 5-2)
- Effectiveness parameter selection analysis (paragraphs 3-6, 4-2, and 5-2)
- System and cost effectiveness analysis (paragraphs 3-7, 4-2, and 5-2)

The characteristics of these analyses are described for Concept Formulation, Contract Definition, and Acquisition in the above-referenced paragraphs. Additionally, the nature of the analysis results to be documented and reported are delineated in paragraphs 3-9, 4-5, 5-3, and 5-4 of the manual.

6-3 CONTRACTOR MANAGEMENT

The efficient and effective management implementation of the system and cost effectiveness process by participating contractors will require an authoritative perspective of the involved technical elements and procedures and their mutual dependencies with those of both the system program management and systems engineering management processes associated with a particular system procurement. Since the procedures of the manual are based on the efficient channeling of engineering data and analyses to provide an overall perspective of the system technical-cost-time performance, the degree that the activities, analyses, and data elements are properly integrated will be a major factor in the success of the system program involved.

Implementing the Effectiveness Process

The manual basically is addressed to how the effectiveness process typically is implemented on a time basis for any class of Air Force systems. The management action for this important program consideration involves the judicious selection of the major activities to be timely implemented and to insure that the depth of implementation is consistent with the total program scope and cost.

Planning for Data

The procedures of the manual are based on the maximum use of engineering data normally generated during a typical system program, with a minimum need for additional data. Careful preplanning and redirection of the scheduled analyses, studies, tests, and similar data sources will be required to insure their maximum usability for effectiveness evaluations. The total data requirement for effectiveness evaluations is a composite of the individual data needs described in each step of the process.

Organizing for Management of the Effectiveness Function

It is vital that contractor overall management of the effectiveness function be established at an authoritative program level and properly structured. The responsibility should be assigned to a single organization. This does not imply the requirement for a new or separate organization for system effectiveness.

Chapter 7

APPLICATION GUIDELINES FOR SPECIFIC MAJOR CLASSES OF AIR FORCE SYSTEMS

Summary

Application guidelines are provided for the aircraft, ballistic missile, booster, satellite, command and control, and warning and detection classes of Air Force systems. For each system class, major technical elements of the effectiveness structure are translated in terms of current system performance and design criteria, analyses, and terminology to provide the Air Force and contractor managers with an authoritative perspective of the technical correspondence present. Effectiveness elements that are translated include (1) mission objectives, (2) mission conditions, (3) Figures of Merit, (4) effectiveness parameters, (5) top-level system functions, (6) system parameters, (7) accountable factors, (8) transfer functions, (9) cost effectiveness measures, and (10) analyses.

7-1 GENERAL

This chapter provides application guidelines for major classes of Air Force systems. Included are guidelines for the following system classes:

- Aircraft
- Ballistic missile
- Booster
- Satellite
- Command and control
- Warning and detection

Two prerequisites are fundamental to the efficient implementation of the system and cost effectiveness technology. These are:

- Having an overall perspective of the system and cost effectiveness implementation concepts, technical elements, and management process involved.

- Having an intelligence of how the implementation concepts, technical elements, and management process of the effectiveness technology can be related specifically to the mosaic of current system performance and design criteria, analyses, and terminology for a particular application.

Prior chapters of this manual were addressed to the first of the two implementation prerequisites. The contents of these chapters were directed at providing Air Force and contractor program managers with a broad perspective of the general concepts, technical elements, and procedures that can be practically and validly applied to implement the effectiveness technology during Concept Formulation, Definition, and Acquisition. Additionally, an overview was provided of the interactions of the effectiveness elements and procedures with the AFSC system program management procedures and systems engineering management procedures. This chapter is intended to provide further insight into the correspondence and required translations of the effectiveness technical elements to the spectrum of current system performance and design criteria, analyses, and terminology. This is the second prerequisite for implementation efficiency. For each class of Air Force systems, representative translations are provided for the following system and cost effectiveness technical elements:

- Mission objectives
- Mission conditions
- Figures of Merit
- Effectiveness parameters
- Top-level system functions
- System parameters
- Accountable factors
- Transfer functions (in terms of input-output variables)
- Cost effectiveness measures
- Analyses

The representative translations are intended as guides and, thus, are broadly formulated so as to be of general applicability to, and characteristic of, most systems in the system class. For any application, the translations must be in terms of specifically applicable and measurable system performance and design criteria.

The specialty technical parameters represent a category of system performance parameters that is universally applicable to all major systems, independent of

system class, with only the prescribed parameter values and some accountable factors being different from one system to another. Because of this commonality, these parameters and their accountable factors are separately listed in paragraph 7-2 to follow. A transfer function can be established for each parameter listed, to relate the output values of the parameter to the ensemble of input values for its applicable set of accountable factors.

7-2 COMMON SPECIALTY TECHNICAL PARAMETERS

Parameter	Accountable Factor
• Mission reliability	failure rates mission time alternate modes of operation override capabilities
• Safety	hazardous failure rates fail-safe devices human factors special equipment
• Survivability	exposure time reaction time dispersal radius hardening level countermeasures alternate modes of initiation
• In-operation maintainability and repairability	time constraint accessibility number of spares override capabilities adjustment capabilities mean time to repair/replace special skills
• Penetrability	decoys hardening level countermeasures angle of attack exposed surface
• Security	communication characteristics transmission time duration coding characteristics command and control sequencing

Parameter (Continued)	Accountable Factor (Continued)
• Vulnerability	armament protective capabilities neutralizing capabilities angle of attack flight path profile warning time electromagnetic interference and radiation
• Abort reliability	mean time to a critical failure redundancies override capabilities adjustment capabilities
• Human performance	frequency of tasks time for tasks operation exposure time accessibility special skills
• Availability	basic maintenance policy level and location of maintenance level and location of spares alert conditions number of installations, sites, and operating locations reaction time warning time operational schedules number of systems in Wing inspection time fraction of total time in operation installation and checkout time checkout equipment maintenance time checkout failure rates inventory fill rates removal rates organizational, depot, and field time required for maintenance transportation time time required for mission interfaces with augmenting systems special handling facilities number of Wing level personnel allocated
• Maintainability	mean and maximum time to repair time constraints for preventive maintenance type and level of maintenance personnel by specialty skills

Parameter (Continued)	Accountable Factor (Continued)
• Maintainability (Continued)	mean and maximum time between failures mean and maximum preventive maintenance time mean and maximum corrective maintenance time maintenance activity sequencing administrative and supply down time

7-3 AIRCRAFT

A. Mission Objective

1. Transport System

   The system shall be capable of providing air lift capability of cargo/personnel at high subsonic speed within a prescribed time.

2. Bomber System

   The system shall be capable of delivering a specified payload to an assigned target on time and within prescribed accuracy and to return to base point.

3. Tactical System

   The system shall be capable of providing timely close air support for ground troops, providing air escort for tactical bombers, bombing tactical targets, and flying reconnaissance missions.

4. Interceptor System

   The system shall be capable of destroying engaged enemy aircraft at high subsonic speed.

B. Mission Condition (Other Than Natural Environment)

Acoustic noise
Altitude pressure
Electromagnetic interference

Temperature
Angular oscillation
Sustained acceleration
Vibration
Shock
Radiation

C. Figure of Merit (FOM)

1. Transport System FOM

Expected number of ton miles to be carried per unit of time.

Expected time required to deliver a designated strategic cargo to a specified destination and return.

2. Bomber System FOM

Probability of destroying (n) targets with (x) number of sorties.

Probability of (n) bombs dispersed within an (x) radius on a target of (y) hardness with (z) aircraft.

3. Tactical System FOM

Probability of providing timely troop support over (n) distance with (x) number of sorties.

Expected number of sortie missions which can be completed with a fixed force.

4. Interceptor System FOM

Probability of destroying (n) out of (m) enemy aircraft of a specified type per engagement.

Expected number of aircraft targets of a given size and type which can be neutralized with (n) number of sorties.

5. General Aircraft System FOM

Expected number of training missions which can be completed per month.

6. General Aircraft Subsystem FOM

Probability of achieving a specified thrust with (n) engines over (t) time.

Probability that the navigation subsystem will perform to a specified accuracy over (t) time.

Expected accuracy of fire control subsystem under visual or all-weather conditions.

Expected lethality of on-board armament for a specified target posture.

Expected number of UFH/VFH communication channels operating at a specified power rating over (t) time.

Probability of identifying a target of type (x) and delivery of payload to target within (t) time during an (n) hour missions.

D. Effectiveness Parameter

1. Availability

The expected number of aircraft that are in-commision to proceed to a tactical mission at any random instant of time.

Available flight hours per month.

2. Dependability

Given the availability state, the expected number of aircraft that can successfully complete a mission when commanded.

3. Capability

Given the availability and dependability states, the expected number of aircraft systems that will operate within specified system parameter tolerances in meeting their objectives, e.g., within specified values of range, cruise speed, rate of climb, etc.

NOTE: The effectiveness parameters may also be expressed in terms of probability.

E. Top-Level System Function

Propulsion
Flight control (manual and automatic)
In-flight refueling
In-flight malfunction detection
Cargo air drop
Navigation
Communication
Target destruction
Takeoff
Cruising
Flight maneuvering
Terrain avoidance
Target identification
Payload delivery
Instrument landing
Visual landing
Auxiliary power delivery
Environmental control
Loading

F. System Performance Parameter

1. Functional Parameter

Range
Payload capacity

Rate of climb
Speed (cruise, stall, takeoff, landing)
Altitude (initial cruise)
Maneuverability
Lethality
Takeoff and landing distance
Center of gravity envelope
Stability and control characteristics
Buffet boundary
Braking coefficient
Cooper rating
Auxiliary power load
Cargo air drop tonnage
Turnaround time
Liftoff weight
Drag (takeoff, cruise, landing)
Lift coefficient (takeoff and landing maximum)
One-engine-out climb rate
Weight (empty, operating)
Operating weight center of gravity
Thrust (installed takeoff, climb, cruise)
Maximum reverse thrust
Stall pattern indicator (cruise, takeoff, landing)
Installed cruise thrust specific fuel consumption
Structural limit weight at specified load factors
Roll in (t) time
Air minimum control speed
Roll helix angle
Lateral directional damping
Longitudinal short period damping
Temperature in flight
Flotation
Main power load
Hydraulic load

2. Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

G. Accountable Factor

1. Accountable Factor for Functional Parameter

Takeoff thrust
Static thrust
Nacelle configuration
Pylon configuration
Thrust reverser characteristics
Equilibrium angle of attack
Sideslip angle
Angle of bank
Air velocity
Center of gravity
Monents and products of inertia
Aerodynamic forces
Gravity
Applied moments about aircraft axes
Aircraft roll, pitch, and yaw rates
Wing area
Aileron configuration
Spoiler characteristics
Trailing edge profile
Angle of attack
Shape of aircraft
Reynolds number
Mach number
Heading Euler angle
Horizontal tail profile and area
Vertical tail profile and area
Elevator profile

Rudder characteristics
Velocity
Target area
Landing field characteristics
Search pattern
Leading edge flaps – inboard
Lift and drag coefficients
Weight (takeoff and landing)
Air density
Fuel consumption rate
Maximum frontal area
Reaction time

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors. For example, the accountable factor of leading edge flaps – inboard is influenced by area, location span, maximum deflection, percent of surface ahead of hinge line, type of surface, rate of deflection, sweep angle of hinge line, equivalent root chord length, equivalent tip chord length, mean chord length, mean chord location, and percent of wing affected.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. Transfer Function (Output Parameter as a Function of Input Accountable Factor)

Parameter	Accountable Factor
1. Range	weight (final) weight (initial) wind air density lift coefficient drag coefficient surface area fuel capacity rate of fuel flow thrust
2. Takeoff and landing distance	pilot technique ground condition airplane altitude drag coefficient thrust speed weight lift coefficient
3. Rate of climb	roll, pitch, and yaw rates sideslip angles lift coefficient dynamic pressure wing area velocity thrust drag coefficient weight
4. Lift	angle of attack surface area of wing shape of aircraft velocity air density Reynolds number Mach number lift coefficient
5. Drag	drag coefficient maximum frontal area angle of attack velocity air density

Parameter (Continued)	Accountable Factor (Continued)
6. Cruise speed	weight dynamic pressure surface area lift coefficient thrust drag coefficient

I. Cost Effectiveness Measure

1. Transport System

Expected number of consecutive deliveries of specified cargo to its destination within (x) hours per unit cost of delivery.

Expected number of ton miles of general cargo transported per unit of cost.

Minimum cost-time product required to deliver a specified cargo

2. Bomber System

Expected number of point targets destroyed per unit of cost.

Expected number of alert missions per unit of cost.

3. Tactical System

Expected number of close air supports per unit of cost.

Expected number of successful tactical bombing missions per unit of cost.

Expected number of successful reconnaissance missions per unit of cost.

Expected number of successful air escort missions per unit of cost.

4. Interceptor System

Expected number of enemy aircraft destroyed per unit of cost.

5. General Aircraft System

Expected number of hours of training accomplished per unit of cost.

Expected cost of sustaining a specified force level per year for a specified system effectiveness value.

J. Analysis

Payload vs range
Takeoff distance vs gross weight
Landing distance vs gross weight
Altitude vs rate of climb for various gross weights
Airplane limit load factor vs Mach No.
Drag rise vs Mach No.
Power required vs speed
Velocity vs rate of roll
Stick force vs velocity for different tab angles
Elevator floating angle vs angle of attack
Hinge moment vs angle of attack
Elevator angle vs lift coefficient
Thrust required vs speed
Variation in lift and drag vs Mach No.
Cruise speed vs range
Cruise drag coefficient change vs range
Range vs operating weight
Weight vs take-off distance over 50 feet
Air speed vs weight
Gross weight vs center of gravity
Cargo load vs fuselage station
Altitude vs equivalent air speed
Landing distance vs weight
Altitude vs range
Damping parameter vs rolling parameter

7-4 BALLISTIC MISSILE

A. Mission Objective

The system shall be capable of delivering a payload to a specified target within a designated time, detonate, and do a prescribed amount of damage.

B. Mission Condition (Other Than Natural Environment)

Acoustic noise
Altitude pressure
Electromagnetic interference
Temperature
Angular oscillation
Sustained acceleration
Vibration
Shock
Radiation
Jamming
Enemy intercept threat

C. Figure of Merit (FOM)

1. System FOM

   Probability of destroying a prescribed target of (x) hardness in (t) time with (n) targeted missiles.

   Expected number of targets destroyed of (x) hardness with (n) or less missiles.

   Expected level of damage to an (x) hardened target with (n) or less missiles in (t) time.

2. Subsystem FOM

   Probability that the missile guidance system will perform to a specified in-flight accuracy for a specified time.

Probability that the payload will impact on target for a specified re-entry profile.

Probability of achieving a specified thrust for each of (n) stages over (t) time.

Probability of achieving a specified post-boost maneuver within (t) time.

D. Effectiveness Parameter

1. Availability

The expected number of missiles that are ready to proceed to the launch phase at any random instant of time.

2. Dependability

Given the availability state, the expected number of missiles that can be launched successfully and delivered to the target area when commanded.

3. Capability

Given the availability and dependability states, the expected number of missiles that will operate within specified system parameter tolerances in meeting their objectives, e.g., within specified limits of range, height of burst, circle of equal probability, lethality, etc.

NOTE: The effectiveness parameters may also be expressed in terms of probability.

E. Top-Level System Function

Launch
Propulsion
Guidance and control
Staging
Payload delivery
Target destruction
Environmental control
Maneuvering

F. <u>System Performance Parameter</u>

1. Functional Parameter

Range
Payload capacity
Velocity
Maneuverability
Lethality
Center of gravity envelope
Stability and control characteristics
Liftoff weight
Drag
Weight
Thrust
Pitch, yaw, and roll
Temperature in flight
Main power load
Hydraulic load
Accuracy
Altitude
Trajectory
Attitude control variables

2. Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

G. <u>Accountable Factor</u>

1. Accountable Factor for Functional Parameter

Takeoff thrust
Static thrust
Specific impulse
Air velocity
Center of gravity

Moments and products of inertia
Aerodynamic forces
Gravity
Roll, pitch, and yaw rates
Velocity
Target area
Air density
Fuel consumption or burn rate
Reaction time
Propellant weight
Thrust vector control variables
Thrust termination characteristics
Chamber pressure
Burnout velocity
Burnout angle
Lofting angles
Exhaust velocity
Impulse-weight ratio
Time on target
Vapor sensing characteristics
Pre-flight pressure characteristics
Pre-launch mass properties
Thrust termination time
Timing errors
Loop gain
Bending loads
Angular velocity
Gyro drift errors
Mass properties tolerances
Payload weight
Drag loss
Arming and fuzing time
Expended inert weight
Lethal radius

Target posture and dispersal patterns

Target sensing

Burst pattern

Optional fuze set

Angle of attack

Maximum frontal area

Earth's radius

Inertial platform alignment

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. Transfer Function (Output Parameter as a Function of Input Accountable Factor)

Parameter	Accountable Factor
1. Range	weight wind air density drag coefficient propellant capacity burn rate engine balancing lofting characteristics apogee altitude velocity angle pitch program thrust burnout velocity
2. Accuracy	wind velocity burnout variables earth rotation acceleration vehicle velocity lofting gyro drift guidance errors
3. Circle of equal probability (CEP)	range errors track errors

Parameter (Continued)	Accountable Factor (Continued)
4. Thrust	thrust coefficient nozzle throat area chamber pressure characteristic exhaust velocity
5. Specific impulse	exposed burning surface propellant linear burn rate propellant density effective propellant weight
6. Total impulse	specific impulse hot gas weight flow rate burn time residual propellant thrust buildup inefficiencies
7. Overall rocket performance	thrust specific impulse total impulse
8. Time of flight	pitch command cutoff velocity distance to target aerodynamic coefficients re-entry vehicle ballistic coefficients
9. Lethality	radius of ordnance effect height of burst ordnance concentration target profile

I. Cost Effectiveness Measure

Minimum cost of destroying a prescribed target of (x) hardness with a prescribed probability of kill.

Expected number of targets of (x) hardness destroyed per unit of cost.

Expected dollar value, strategic value, or percent of damage to enemy property per unit of cost.

Cost per missile on target for a specified probability of success.

J. Analysis

Range vs theoretical burnout velocity

Mach number vs drag coefficient

Time vs roll moment
Motor pressure vs vector angle
Time vs launch pressure
Time from launch vs cold wall heat rate
Mission time vs velocity
Gross weight vs distance
Payload vs range
Velocity vs altitude
Total impulse vs vehicle gross weight
Thrust vs velocity
Gross weight vs center of gravity
Trajectory

7-5 BOOSTER

A. Mission Objective

The system shall be capable of directly injecting payloads of specified weights into circular orbit from x_1 to x_2 nautical miles altitude and into any point on the conic of elliptical orbits whose perigees and apogees are no less than y_1 nautical miles and no greater than y_2 nautical miles.

B. Mission Condition (Other Than Natural Environment)

Acoustic noise
Altitude pressure
Electromagnetic interference
Temperature
Angular oscillation
Sustained acceleration
Vibration
Shock
Radiation
Buffeting and loads

C. Figure of Merit (FOM)

1. System FOM

Probability of injecting a satellite vehicle of (x) pounds into a y-degree orbit of (z) nautical mile altitude at (t) time.

Expected number of successful repeat missions for which the booster can be utilized.

2. Subsystem FOM

Probability of achieving a specified thrust at any random instant of time.

D. Effectiveness Parameter

1. Availability

The probability of the booster system being ready to proceed to the launch phase at any random instant in time.

2. Dependability

Given the availability state, the probability of the booster system to inject a payload into a specified orbit.

3. Capability

Given the availability and dependability states, the probability of the booster operating within specified system parameter tolerances in meeting their objectives, e.g., within specified values of accuracy and time.

E. Top-Level System Function

Launch
Propulsion
Steering and stability control
Staging
Orbital injection
Thrust vector control

F. System Performance Parameter

1. Functional Parameter

Ascent attitude rates
Satellite vehicle separation conditions
Mixture ratio
Altitude thrust
Altitude specific impulse
Chamber pressure
Thrust buildup rate
Injection accuracy
Thrust
Specific impulse
Operation over mixture ratio range
Operating cycle
Engine start time
Chamber pressure buildup time in vacuum
Thrust unbalance
Thrust overshoot
Differential shutdown impulse
Engine shutdown
Chamber alignment under zero thrust
Dynamic characteristics
Liftoff weight
Electrical power
Propellant start consumption
Thrust decay rate
Total shutdown impulse
Thrust vector control angular travel
Thrust vector misalignment
Gimbaling limitations
Autogenous pressurization
Nozzle cant

2. Specialty Technical Parameter

Launch reaction time
Launch hold time
Abort reaction time
Turnaround time
Launch rate
Launch window
(See additional listing in paragraph 7-2 of this chapter.)

G. Accountable Factor

1. Accountable Factor for Functional Parameter

Takeoff thrust
Static thrust
Center of gravity
Moments and products of inertia
Aerodynamic forces
Gravity
Roll, pitch, and yaw rates
Air density
Fuel consumption or burn rate
Effective burning time
Propellant weight
Thrust vector control characteristics
Thrust termination
Chamber pressure oscillations
Burnout velocity
Burnout angle
Exhaust velocity
Impulse-weight ratio
Vapor sensing
Pre-flight pressure characteristics
Nozzle expansion ratio
Propellant density
Cutoff time

Total time, liftoff to injection error

Dynamic loads

Angular velocity

Thrust coefficient

Mass properties tolerances

Payload weight

Drag loss

Expended inert weight

Angle of attack

Nozzle throat area

Altitude errors

Earth's radius

Inertial platform alignment

Hot gas weight flow

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. Transfer Function (Output Parameter as a Function of Input Accountable Factor)

Parameter	Accountable Factor
1. Ascent attitude rates	roll rate pitch rate yaw rate
2. Injection accuracy	in-track velocity error flight path angle error orbital inclination error altitude error cross-track position error total time, liftoff to injection error
3. Satellite vehicle separation conditions	pitch error relative to velocity error yaw error relative to velocity error roll error relative to local vertical attitude rates about pitch or yaw axis attitude rates about roll axis
4. Thrust	thrust coefficient nozzle throat area chamber pressure characteristic exhaust velocity

Parameter (Continued)	Accountable Factor (Continued)
5. Specific impulse	exposed burning surface propellant linear burn rate propellant density effective propellant weight
6. Total impulse	specific impulse hot gas weight flow rate burning time residual propellant thrust buildup inefficiencies
7. Overall rocket performance	thrust specific impulse total impulse

I. Cost Effectiveness Measure

Expected cost per pound of initial payload weight placed into orbit.

J. Analysis

Wind speed vs altitude

Velocity vs altitude

Frequency vs gain

Motor pressure vs vector angle

Time vs launch pressure

Mission time vs velocity

Total impulse vs vehicle gross weight, altitude, velocity

Thrust vs velocity

Velocity vs burnout angle

Burnout altitude vs burnout angle

7-6 SATELLITE

A. Mission Objective

The system shall be capable of transmitting information at a specified rate and perform priority selection and schedule transmissions in accordance with priority rankings.

B. <u>Mission Condition (Other Than Natural Environment)</u>

Acoustic field
Pressure/altitude
Vibration
Shock
Sustained radiation
Temperature
Electromagnetic interference
Sustained acceleration
Angular oscillations

C. <u>Figure of Merit (FOM)</u>

1. System FOM

Probability of receiving and transmitting high priority information within (x) seconds at prescribed frequency ranges.

Expected number of low priority messages received and transmitted per month within prescribed frequency ranges.

2. Subsystem FOM

Expected number of SHF and VHF channels operating at a specified effective radiated power for (n) years.

Probability that the satellite control subsystem will perform to a specified accuracy over (t) time.

Probability that the electrical power subsystem will provide (x) watts to the communication and telemetry subsystems for a minimum of (n) years.

D. <u>Effectiveness Parameter</u>

1. Availability

The probability that the satellite is ready to proceed to the launch phase at any random instant of time.

2. Dependability

Given the availability state, the probability that the satellite will transmit messages upon command.

3. Capability

Given the availability and dependability states, the probability that the satellite will operate within specific system parameter tolerances in meeting their objectives.

E. Top-Level System Function

Dispense payload
Achieve operating altitude and station
Sustain orbital position and attitude
Provide electrical power
Receive and transmit information
Generate and transmit beacon signals
Thermal control

F. System Performance Parameter

1. Functional Parameter

Antenna beam pointing
Stabilization (spin or 3 axis)
Power characteristics
Separation
Attitude control and reference
Satellite injection
Solar cells deployment
Antenna deployment
Shroud separation
Apogee motor separation
Thrust (apogee motor)
Horizon sensing
Coarse thrust control

Fine damping
IF filtering
Payload capacity
RF signals
Effective radiated power
Frequency characteristics
Amplitude response
Phase response
Signal suppression
Beacon characteristics
Telemetering
Center of gravity envelope
Steady state specific impulse
De-spin
Signal conditioning

2. Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

G. Accountable Factor

1. Accountable Factor for Functional Parameter

Specific impulse (apogee motor)
Average thrust (apogee motor)
Shroud separation
Separation of launch vehicle adapter
Polarization
Beacon signal level
Antenna coverage
Spin rate
Beacon frequency
Propellant containment characteristics
Channel capacity
Battery charging

Power distribution
Power discharge and duty cycle
Impedance
Operating range
Intermittent load requirements
Power shunting
Frequency range
Tone modulation
Frequency modulation
Frequency accuracy
Frequency stability
Single signal level
Amplitude response
Phase response
Tone frequency spacing
Beacon incidental phase modulation
Beacon interference
Thermal noise power
Spurious signals
Pulse interference
Output radiation
Bit coding
Bit rate
Word rate
Frame rate
Frame synchronous word
Data word
Satellite identification word
DC voltage and current channels
RF power channels
Temperature channels
Telemetry calibration reference

Telemetry bus voltage
Sensing voltage (dummy load)
Decoding (despin and spin)
Range filtering
Input filtering
RF switching
Tunnel diode amplification
Local oscillation
UHF isolation
Output isolation
Variable attenuation
Interstage filtering
Input multiplexing

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. Transfer Function (Output Parameter as a Function of Input Accountable Factor)

Parameter	Accountable Factor
1. RF signal	signal level capacity polarization
2. Effective radiated power	single signal beacon signal antenna coverage
3. Frequency characteristics	frequency range beacon frequency center frequency of transient passband stability (long term) stability (short term) stability (temperature)

Parameter (Continued)	Accountable Factor (Continued)
4. Overall amplitude response	frequency variation power output variation receiver input signals amplitude variation degradation from thermal noise
5. Satellite identification frequency	spacing between tone frequency frequency stability (one year) frequency stability (one second) frequency stability (temperature) initial frequency accuracy
6. RF output characteristics	effective radiated power frequency range frequency stability frequency accuracy polarization
7. Telemetry accuracy	DC voltage and current channels RF power channels temperature channels telemetry calibration reference
8. Orbital stability	latitude longitude altitude velocity

I. Cost Effectiveness Measure

Expected number of consecutive successful attempts to transmit a high priority message within (x) seconds per unit of cost.

Expected number of bits of low priority messages transmitted per unit of cost.

Expected number of channel-years per unit of cost at a minimum specified effective radiated power.

J. Analysis

Fixed vs oriented solar arrays

Spray coating vs cover slip of solar arrays

Surface tension screens vs metallic, elastomer diaphragm

Shunt vs series switching

Magnesium vs magnesium-thorium structure
Body spin vs wheel launch vehicle
Stabilization wheel size vs angular momentum
Stabilization wheel size vs solar pressure compensation
Select vs fine fixed thruster arrangements
Synchronous elliptical apogee vs low circular altitude

7-7 COMMAND AND CONTROL

A. Mission Objective

The system shall be capable of locating an orbiting vehicle, provide remote operation and control of the vehicle and payload subsystems, and provide communication to and from the orbiting vehicle.

B. Mission Condition (Other Than Natural Environment)

Temperature
Electromagnetic interference
Jamming
Radiation
Shock
Vibration

C. Figure of Merit (FOM)

1. System FOM

   Probability that the system will operate continuously for (t) time and locate an orbiting satellite at a given point in time, transmit commands to and receive data from the satellite, spatially correlate the data when required, and control and operate the satellite and payload when required.

2. Subsystem FOM

   Probability that (n) remote tracking stations will locate, track, receive and transmit at any random point in time.

D. Effectiveness Parameter

1. Availability

Probability of the command and control system being ready to proceed to the operational mode at any random instant of time.

2. Dependability

Given the availability state, the probability that the command and control system will operate to provide support to (n) satellite systems for a period of (t) time.

3. Capability

Given the availability and dependability states, the probability that the command and control system will operate within specified system parameter tolerances to accomplish each of the following when required:

- control traffic up to (n) satellites
- receive (y) quantity of data in a prescribed frequency range from (n) satellites within (t) time
- process (y) quantity of data from (n) satellites within (t) time
- transmit (x) command decisions to (n) satellites within (t) time.

E. Top-Level System Function

Orbit determination and prediction

Acquisition and tracking of orbiting vehicle

Command and control of satellite

Data processing

Malfunction detection

F. System Performance Parameter

1. Functional Parameter

Range

Accuracy

Tracking

Recovery force control
Communications control
Mode generation
Orbit determination
Command generation
Command selection, monitor, control, execution
Data base generation
Telemetry/tracking data processing
Remote tracking
Commanding transmission
Commanding verification
Telemetry playback
Tracking history playback
Telemetry data compression
Picture definition
Synchronizing
Command prediction
Mode and picture generation
Storage capacity
Real time display modification
System initialization and recovery
On-line load monitoring
Bulk storage loading
Data base control
Data base display

2. Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

G. Accountable Factor

1. Accountable Factor for Functional Parameter

Raw tracking data
Tracking data recording rates
Pointing data
Range rate
Ranging data

Radiated electromagnetic signals
Data compression
Data routing
Search patterns
Data lines
Orbit data
Number of channel paths
Command rate, loading, storage, formating, mode, and sequence
Real time control messages
Telemetry signals
Antenna information comparisons
Data sorting and synchronization
Transmitting rate
Verification rate
Data processing rate
Information rate
Antenna position
Signal maximum rise time
Signal maximum fall time
Computer controlling capabilities
Computer interface equipment capabilities
Signal characteristics
External load impedance
Source impedance
Frame length
Slave bus directing capacity
Estimated time to acquisition
Estimated time to track
Antenna position range
Number of commands to be transmitted
Display capacity
Processing mode capacity
Monitoring capacity
Signal strength
Voice transmission data characteristics

Input ready signals

Output resume signals

Signal duration

Response time

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. Transfer Function (Output Parameter as a Function of Input Accountable Factor)

Parameter	Accountable Factor
1. Tracking	slave bus directing capacity estimated time to acquisition estimated time to track antenna position range data processing rates (real time) antenna information comparisons antenna position range and range rate
2. Commanding	number, sequence, and timing of commands to be transmitted number of correct verifications echo signals (results and alarms) transmission mode for specific commands
3. Telemetering	display capacity processing mode capacity monitoring capacity signal strength and quality telemetry processing modes (prepass or real time) telemetry mode processing variables voice transmission data characteristics telemetry data range
4. Data processing (telemetry)	number of data signal inputs input ready signals output resume signals logic signal characteristics signal maximum rise time signal maximum fall time

Parameter (Continued)	Accountable Factor (Continued)
4. Data processing (telemetry) (Continued)	input impedance voltage number of data outputs input request signals information ready signals function ready signals normal channel signal characteristics buffer channel signal characteristics external load impedance

I. Cost Effectiveness Measure

Expected number of stored bits of information which can be retrieved within a specified time per unit of cost.

Expected number of satellites which can be supported for a prescribed period of time per unit of cost.

Cost per hour of real time operation.

J. Analysis

Geographic vs geocentric latitude

Probability of acquisition vs integrated signal-to-noise ratio

Probability of acquisition vs range

Signal-to-noise ratio vs range

Attenuation vs wavelength

Background temperature from atmosphere vs cosmic noise

Rehearsals

7-8 WARNING AND DETECTION

A. Mission Objective

The system shall be capable of detecting, warning, and tracking aircraft and missiles within a prescribed range, accuracy, and time delay.

B. Mission Condition (Other Than Natural Environment)

Acoustic noise

Radiated noise

Jamming

Electromagnetic interference

Temperature

Vibration

Shock

C. Figure of Merit (FOM)

1. System FOM

Probability of detecting an object given that (n) tracks are in process.

Probability of successfully completing a track, given detection.

Expected number of tracks which can be performed simultaneously within a prescribed accuracy.

Probability of acquiring a given target within (t)time or within (x) number of scans.

2. Subsystem FOM

Probability of the antenna efficiency factor being within x_1 to x_2 percent.

D. Effectiveness Parameter

1. Availability

The probability that the system is in a ready state at any random point in time for continuous operation.

2. Dependability

Given the availability state, the probability that the system will operate properly at any random instant of time.

3. Capability

Given the availability and dependability states, the probability that the system will accurately detect, warn, and track an airborne object at minimum range (x) to maximum range (y).

E. Top-Level System Function

Transmitting

Receiving

Scanning

Detecting and tracking

Ranging

Target identification

Data processing

Control center data communications network

F. System Performance Parameter

1. Functional Parameter

Angle of sector coverage (horizontal and vertical)

Beam steering

Beam switching

Range radius

Azimuth angular accuracy

Operating frequencies

Maximum radar range

Target acquisition accuracy

Tracking accuracy

Communications (alert) control

Signal-to-noise ratio

Strobe and display scale

Data base display

Data base control

Height identification

Tracking stability

Track count

Number of radar inputs

Number of simultaneous intercepts

Time delays

Weapon target separation

Digital data link

Message processor

Controller comparator

2. Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

G. Accountable Factor

1. Accountable Factor for Functional Parameter

Maximum range
Minimum range
Peak power output
Pulse repetition rate
Pulse duration
Minimum detectable received signal level
Antenna gain
Antenna azimuthal/elevation beamwidth
Antenna azimuthal/elevation scan rates
Receiver gain
Receiver channel bandwidth
Receiver sensitivity
Unambiguous range
Voltage level
Receiver recovery time
Azimuth bearing
Range rate
Doppler resolution
Peak power
Average power and maximum average power
Frequency range
Input signal range
Voltage threshold
Dynamic range
Input impedance
Output signal discernability range
Selection range of open channels
Pulse shape
Power output variation
Leakage resistance
Waveshapes
Electrical continuity
Pulse length

Voltage standing wave ratio
Side lobe and back lobe levels
Beam switching time
Frequency response
Signal integration time
Signal processor gain
Transmitter power output
Blip/scan ratio
Harmonic distortion
Intermodulation
Linearity (converter, multiplexer, analog)
Spurious signal level
Transmitter pulse width
Signal amplitude
Pulse rate per second
Thermal noise
Antenna rotation characteristics
Scan speed
Target area, speed, heading, position, count
Target distance
Antenna reflected area
Received power
Transmitted peak power
Effective aperture area
Transmitter frequency

NOTE: Each of the accountable factors listed can be broken down to the next lower level of accountable factors.

2. Accountable Factor for Specialty Technical Parameter

(See listing in paragraph 7-2 of this chapter.)

H. <u>Transfer Function (Output Parameter as a Function of Input Accountable Factor)</u>

Parameter	Accountable Factor
1. Target acquisition accuracy	range azimuth bearing range ratio acceleration target course and count

Parameter (Continued)	Accountable Factor (Continued)
2. Tracking accuracy (radar)	doppler resolution azimuth angular accuracy frequency peak power average power pulse length pulse repetition rate antenna gain signal integration time signal processor gain
3. Signal-to-noise ratio	beacon antenna gain signal loss transmitter power target range radar wavelength
4. Scattering	radar wavelength radius of object
5. Detection	threshold voltage amplitude of signal or noise
6. Maximum radar range	noise factor signal-to-noise ratio equivalent noise bandwidth temperature of signal source system loss factor power gain radar wavelength transmitter power target cross section

I. Cost Effectiveness Measure

Minimum cost of detecting and tracking an object for a specified probability.

Expected number of track-hours with a specified accuracy of track per unit of cost.

J. Analysis

Altitude vs range

Filter matching losses for peak vs average signal

Loss (db) vs number of range elements observed

Loss (db) vs noise deflection

Attenuation vs frequency

Velocity vs range

Amplitude vs range
Normalized thermal noise error vs signal-to-noise ratio
Target location vs position error, velocity error
Tracker elevation angle error vs range
Multipath error relationships
Scanning loss vs scan speed
Live interceptions
Simulated interceptions

Appendix A

EXAMPLE OF IMPLEMENTATION PROCEDURES

1. INTRODUCTION

An example is presented herein to illustrate and demonstrate the implementation guidelines and procedures described in the manual for the formulation of criteria and evaluation of system and cost effectiveness during the Concept Formulation Phase. This example follows the step-by-step sequence of effectiveness activities detailed for this phase in Chapter 3, and addresses the analysis of a hypothetical transport aircraft concept. In actual practice, the analysis results would be compared with those of competing system concepts to arrive at a selection decision of the preferred system(s) to be defined in the Definition Phase. This selection decision is based upon many program management factors additional to a system's potential performance and cost stance. Since these factors are beyond the scope of this manual, the selection decision process is not illustrated herein.

A restrictive coverage is provided for the effectiveness criteria formulation and evaluation elements of (1) mission analysis, (2) performance requirements analysis, (3) operational requirements analysis, (4) effectiveness parameter selection, (5) model structuring, and (6) system and cost effectiveness analysis. This is to simplify the example for ease of understanding since a full illustration of the effectiveness process would be complex for a transport aircraft system. Furthermore, a more complete analysis would entail basically an extension of the procedures illustrated in the example to accommodate a broader spectrum of critical top-level system parameters and accountable factors without materially altering their content.

2. MISSION ANALYSIS

The transport aircraft system is to be designed to fulfill a mission of providing long-range airlift capability at high subsonic speed over any type of route. The system also is to have an all-weather operational capability. Variations of this general mission are considered as different specific missions. These include:

(1) The basic long range mission.
(2) The maximum payload mission with a specified g factor.
(3) The basic payload mission with a specified g factor.
(4) The re-supply mission.

The specific missions are to be accomplished with a minimum of elapsed time and costs. The technical and cost performance potentials of the system for missions (1) and (2) only will be numerically analyzed since the techniques for determining system and cost effectiveness for these two missions typically can be applied to missions (3) and (4).

All missions are to be achieved in the presence of hostile enemy threats and diverse climatic conditions expected to be encountered at any land area where the Air Force will have a mission to move a large and varied quantity of personnel or cargo. For the purpose of the example, the assumed threat levels, threat intensities, probability of each threat occurring, and the average threat intensities postulated to influence system performance, and hence mission outcome, are listed in Table A-1. The average threat intensities currently expected will be used in the effectiveness analysis. Additionally, the example considers only the effect of headwinds and atmospheric density from the following atmospheric conditions typically influencing system performance:

(1) Headwind
(2) Atmospheric density
(3) Tailwind
(4) Crosswind
(5) Temperature
(6) Acceleration of gravity
(7) Atmospheric pressure

TABLE A-1 ASSUMED THREAT LEVELS

Antiaircraft Threat Level	Nominal Intensity	Current		5 Years in Future	
		Probability	Average[(1)] Intensity	Probability	Average[(1)] Intensity
Light (Including no threat)	6.06×10^{-9} lethal rounds per square foot per hour	0.66	$4.0 \times 10^{-9} = L_1$	0.62	3.76×10^{-9}
Moderate	100×10^{-9} lethal rounds per second if no protection	0.18	$18 \times 10^{-9} = L_2$	0.18	18×10^{-9}
Heavy	1.0 milli-roentgen per hour[(2)]	0.16	$0.16 = L_3$	0.20	0.20

(1) Average intensity is obtained by multiplying the nominal intensity of the threat level by the probability of the threat level occurring.

(2) Associated with the effect of a milliroentgen per hour exposure is a probability (R_{AD}) that the aircraft will be disabled during any time it is unprotected.

3. SPECIFYING PRELIMINARY FIGURES OF MERIT (FOMs)

On the basis of the mission analysis, preliminary FOM measures are defined for use in evaluating the performance effectiveness of the system to meet the mission objectives. These measures, which characteristically are grossly definable during Concept Formulation, are:

(1) The probability of achieving a basic long range mission with a specified payload. This is to be at least 0.98 as a goal for a peacetime mission and 0.70 for a wartime mission.

(2) The average number of ton-nautical miles of cargo delivered per aircraft per day over the lifetime of all aircraft in the fleet. This is to be at least 340,000 ton-miles as a goal.

(3) The probability of achieving a maximum payload mission. This is to be at least 0.97 as a goal.

(4) The average number of personnel-miles delivered per aircraft per day over the lifetime of all aircraft in the fleet. This is to be 2,000,000 personnel-miles as a goal.

The system and cost effectiveness analysis illustrated in this example is restricted to the evaluation of FOMs (1) and (2).

4. PERFORMANCE REQUIREMENTS ANALYSIS

All FOMs defined are relatable to critical system functions that must be present for the transport aircraft to accomplish its assigned mission. The extent to which the functions can be achieved is measurable by output parameters of the system. These system parameters, in turn, depend on critical accountable factor inputs. Table A-2 is a listing of typical system parameters, functions, and accountable factors for the hypothetical transport aircraft system, categorized by the effectiveness parameter sets of dependability and capability to which they can be related. The numerical example considers the system parameters of range, maximum payload, cruise velocity, safety, vulnerability, survivability, and reliability. These parameters are associated with the cruising phase of an aircraft's flight profile.

TABLE A-2 SYSTEM PARAMETERS, FUNCTIONS, AND ACCOUNTABLE FACTORS

Parameter	Function	Accountable Factor
Dependability		
• Survivability		Exposure time Reaction time Dispersal radius Hardening level Alternate modes of initiation
• Reliability		Failure rates Mission time Alternate modes of operation Override capabilities
Capability		
• Range	Propulsion	Cruise velocity Specific impulse of fuel
	Aerodynamic lifting	Drag coefficient Wing surface area Lift coefficient Weight-initial, final
	In-flight refueling	Rate of in-flight refueling
• Maximum Payload	Aerodynamic lifting	Cruise lift coefficient Cruise drag coefficient
	Propulsion	Thrust available
	Payload delivery	Volume of compartment Load factor (g) Empty weight
• Cruise Velocity	Aerodynamic lifting	Weight Atmospheric density Wing surface area Cruise lift coefficient Drag coefficient Thrust
• Safety		Hazardous failure rates Fail safe device characteristics Human factors Special equipment characteristics Reaction time

TABLE A-2 SYSTEM PARAMETERS, FUNCTIONS, AND ACCOUNTABLE FACTORS (Continued)

Parameter	Function	Accountable Factor
Capability (Continued)		
• Vulnerability		Armament protective capabilities Neutralizing capabilities Angle of attack Flight path profile Warning time
• Take-off and Landing Distance	Propulsion	Thrust – chamber pressure – area of burn surface – thrust coefficient Speed Coefficient of rolling friction
	Aerodynamic lifting	Take-off lift coefficient Take-off drag coefficient Wing surface area Weight
• Rate of Climb	Aerodynamic lifting	Wing surface area Angle of climb Drag coefficient Weight Lift coefficient Atmospheric density – Altitude – Sea level pressure
	Propulsion	Thrust
• Accuracy of Navigation	Navigation	Accuracy of position and velocity meters Accuracy of guidance
• Cooper Rating	Flight stabilization	Horizontal directional stability Vertical directional stability Roll stability

5. OPERATIONAL REQUIREMENTS ANALYSIS

Major operational parameters influencing availability include:

(1) Average flight hours per day.

(2) Maintenance man-hours per aircraft flight hour.

(3) Average crew size for maintenance.

All of these parameters are included in the numerical effectiveness analysis.

6. EFFECTIVENESS PARAMETER SELECTION

The next step in the effectiveness formulation process is to identify the system parameters and accountable factors, and their values, critically influencing the selected FOMs and, thus, to be addressed in the effectiveness analysis. The critical system parameters and accountable factors to be considered in the example are listed in Table A-3. Sensitivity relationships based on historical design experience which are useful to correlate the influence of accountable factors on system parameters are listed in Table A-4. Some specific numerical relationships will be established in the effectiveness analysis step of the effectiveness process to be illustrated in paragraph 8. All values for system parameters and accountable factors listed in Table A-3 and used throughout the example are hypothetical.

TABLE A-3 CRITICAL SYSTEM PARAMETERS AND ACCOUNTABLE FACTORS

FIGURE OF MERIT (1): Probability of achieving a basic long range mission with a specified payload.

	Assumed Accountable Factor/Parameter Value
Mission Condition	
Intensity of light threat (L_1)	4×10^{-9} round per sq. ft. per hour
Intensity of moderate threat (L_2)	18×10^{-9} round per second
Intensity of heavy threat (L_3)	0.16 milliroentgen
Lethality per milliroentgen (R_{AD})	10^{-7} per milliroentgen
Standard deviation of winds (σ_{RW})	20 knots
Availability (A)	*
Average potential flight hours usable per day ($\overline{F}_t$)	*
Maintenance manhours per aircraft flight hour, minimum ($\overline{M}_{mh}$)	4.0 manhour/hr.
Average crew size for maintenance (C_r)	10 men
Dependability (D)	*
Reliability, minimum	0.98
Reliability, actual	*
Coefficients relating weight to reliability (p_1, p_2, p_3)	0.85, 10^{-6}, 10^{-12}
Coefficients relating weight to survivability (r_1, r_2)	0.02, 0.001
Survivability	*
Capability (C)	*
Expected operating lifetime (T)	300,000 hours
Fuel consumption (c')	0.32/hr.
Drag coefficient due to skin friction (C_{Df})	0.03
Oswald's efficiency factor (e)	1.0

*Denotes a value to be calculated

TABLE A-3 CRITICAL SYSTEM PARAMETERS AND ACCOUNTABLE FACTORS (Continued)

	Assumed Accountable Factor/Parameter Value
Capability (C) (Continued)	
Lift Coefficient (C_L)	0.5
Payload (P_L)	250,000 lb.
Maximum initial weight (W_0)	700,000 lb.
Safety	0.999
Surface area of wings (S)	5,800 sq. ft.
Surface area of aircraft (A_{CRS})	8,700 sq. ft.
Maximum cruise altitude (A_{ltm})	40,000 ft.
Range	4,000 nautical miles
Efficiency of protection against light threat (k_1)	50.0 sq. ft./lb.
Efficiency of protection against medium threat (k_2)	50.0 sq. ft./lb.
Efficiency of protection against heavy threat (k_3)	62.5 sq. ft./lb.
Empty weight excluding weights allocated to reliability, survivability, and protection against threats (W_E)	300,000 lb.
Relative air density (σ)	0.245
Final weight (W_1)	*
Wing span (b)	*
Drag coefficient (C_D)	*
Velocity of flight for maximum range (V)	*
Range in still air (R)	*
Weight allocated to reliability (W_R)	*
Weight allocated to survivability (W_S)	*
Allocation of payload to protection against threats (W_P)	*
FOM (1)	*

*Denotes a value to be calculated

TABLE A-3 CRITICAL SYSTEM PARAMETERS AND ACCOUNTABLE FACTORS (Continued)

FIGURE OF MERIT (2): The average number of ton miles of cargo delivered per aircraft per day over the lifetime of all aircraft in the fleet.

	Assumed Accountable Factor/Parameter Value
Mission Condition	
(Same conditions as for FOM (1))	(Same values as for FOM (1))
Availability (A)	
(Same parameters as for FOM (1))	(Same values as for FOM (1))
Dependability (D)	*
Reliability, minimum	(Same value as for FOM (1))
Reliability, actual	*
Survivability	*
Coefficients relating weight to reliability	(Same values as for FOM (1))
Coefficients relating weight to survivability	(Same values as for FOM (1))
Capability (C)	*
Expected operating lifetime (T)	300,000 hrs.
Surface area of aircraft (A_{CRS})	8,700 sq. ft.
Surface area of wings (S)	5,800 sq. ft.
Maximum cruise altitude (A_{ltm})	40,000 ft.
Fuel consumption (c')	0.32/hr.
Final weight (W_1)	550,000 lb.
Drag coefficient due to skin friction (C_{Df})	0.03
Oswald's efficiency factor (e)	1.0
Lift coefficient (C_L)	0.5
Empty weight excluding weights allocated for reliability, survivability, and protection against threats (W_E)	300,000 lb.

*Denotes a value to be calculated

TABLE A-3 CRITICAL SYSTEM PARAMETERS AND ACCOUNTABLE FACTORS (Continued)

	Assumed Accountable Factor/Parameter Value
Capability (C) (Continued)	
Maximum initial weight (W_0)	700,000 lb.
Efficiency of protection against light threat (k_1)	0.5 sq. ft./lb.
Efficiency of protection against medium threat (k_2)	0.5 sq. ft./lb.
Efficiency of protection against heavy threat (k_3)	0.625 sq. ft./lb.
Safety	0.999
Range	4,000 nautical miles
Relative air density (σ)	0.245
Wing span (b)	*
Drag coefficient (C_D)	*
Payload (P_L)	*
Weight allocated for reliability (W_R)	*
Weight allocated for survivability (W_S)	*
Total Cost (C_0)	*
Average maintenance cost per manhour (C_3)	$10/hr.
Fuel and related cost (C_4)	$0.25/lb.
Fixed daily cost (C_1)	*
Maintenance cost (C_2)	*
Fuel and related cost (C_5)	*
FOM (2)	*
Cost Effectiveness	*

*Denotes a value to be calculated

TABLE A-4 SENSITIVITY RELATIONSHIPS

x pound change in payload = y ton-nautical mile per day*
x unit of survivability = y ton-nautical mile per day*
x pound of protection = y unit of vulnerability*
x pound of protection = y pound of payload*
x foot cruising altitude = y ton-nautical mile per day*
x unit lift coefficient = y foot takeoff distance
x pound payload = y foot cruising altitude
x unit fuel consumption rate coefficient = y nautical mile range*
x foot cruising altitude = y nautical mile range*
x pounds payload = y nautical mile range*
x unit lift coefficient = y nautical mile range*
x unit drag coefficient = y nautical mile range*
x pound of weight = y reliability*
x pound of weight = y survivability*
x unit fuel consumption rate coefficient = y cost per day*
x pound payload = y cost per day*
x unit lift coefficient = y cost per day*
x unit drag coefficient due to skin friction = y cost per day*

*To be derived from numerical analysis of paragraph 8

7. MODEL STRUCTURING

Availability Parameter

For each of the FOMs to be evaluated, availability is measured as the fraction of available daily utilization hours to total daily hours over an extended period of time for a typical aircraft in the fleet. An aircraft is considered available when it is not out-of-commission due to maintenance. (An alternate measure could be based on an aircraft's instantaneous availability, which is the probability that an aircraft will be ready within a prescribed time.) Availability (A) may be expressed as:

$$A = 1 - \frac{1}{24}(\bar{M}_{mh}\,\bar{F}_t/C_r) \qquad (1)$$

where

$\bar{M}_{mh}$ is the number of maintenance manhours per aircraft flight hour

$\bar{F}_t$ is the average potential flight hours usable per day

C_r is the average crew size for maintenance

The quantity $(\bar{M}_{mh}\,\bar{F}_t/C_r)$ in equation (1) represents the average number of hours per day required by a crew of (C_r) men to perform all the maintenance on the aircraft. During this time, the aircraft cannot be utilized. This average number of maintenance hours per day includes both the daily scheduled maintenance time, as well as other maintenance time which may render the aircraft unavailable for extended periods of time. The average number of maintenance hours per day, divided by 24, is then the average fraction of total daily hours that a typical aircraft is unavailable. This is subtracted from 1 to obtain the numerical value for availability.

The potential number of flight hours per day $(\bar{F}_t)$ that a typical aircraft can be utilized is calculated by multiplying the availability measure by 24, namely,

$$\bar{F}_t = 24A \qquad (2)$$

The solution of equations (1) and (2) simultaneously results in the following relation for availability:

$$A = \frac{1}{1 + \bar{M}_{mh}/C_r} \tag{3}$$

Dependability Parameter

For each of the FOMs to be evaluated, dependability is considered as the probability that the aircraft system will continue to function given that it was available at the beginning of the mission. For the example, dependability is structured as the product of the system parameters of reliability and survivability. Reliability for the transport aircraft system is defined as the probability that the aircraft will reach its destination. The goal for reliability is 0.98. Survivability is defined as the probability that either the aircraft will survive all ground threats or that no ground threats exist, subject to the condition that the aircraft is available. Survivability is defined as the probability (P) that the aircraft and crew will survive a hostile ground threat, given that both are available. It is assumed that the aircraft and crew can survive a ground threat if either (1) a moderate or heavy threat is present, but the aircraft and crew can react (including takeoff) within 20 minutes, or (2) only a light threat (including no threat) is present for which it is assumed that in all instances there is sufficient time to react if necessary. Therefore, system dependability can be expressed as:

$$\text{Dependability} = \text{Survivability} \times \text{Reliability} \tag{4}$$

with:

$$\begin{aligned} \text{Survivability} &= P\{\text{Survival}\} \qquad (5) \\ &= P\{\text{A light threat is present}\} \\ &\quad + P\{\text{A moderate or heavy threat is present and reacting within 20 minutes}\} \\ &= P\{\text{Light threat}\} \\ &\quad + P\{\text{Moderate or heavy threat}\}\ P\{\text{Reacting within 20 minutes}\} \\ &= P\{\text{Light threat}\} \\ &\quad + \left[1 - P\{\text{Light threat}\}\right]\ P\{\text{Reacting within 20 minutes}\} \end{aligned}$$

The probability of reacting in 20 minutes is considered to be a function of whether special features are incorporated in the aircraft, such as additional thrust in engines to increase takeoff thrust and/or decrease starting time. Such features are assumed to add weight to the aircraft and affect the capability of the aircraft. This probability can be approximated by:

$$P\{\text{Reacting in 20 minutes}\} = p_1 + p_2 W_S - p_3 W_S^2 \tag{6}$$

where

p_1	is the probability of reacting within 20 minutes without the special features
W_S	is the weight, in pounds, of such special features
p_2 and r_3	are the sensitivity coefficients relating probability of reacting within 20 minutes to the weight of the added features

Similarly, reliability may be represented by a transfer function of the weight effectively allocated to redundant equipment. This transfer function is assumed to be of the form:

$$\text{Reliability} = (0.99)\left(1.0 - r_1 \exp\left|-r_2 W_R\right|\right) \tag{7}$$

where

r_1	is a parameter such that reliability with no redundancy is $0.99\,(1 - r_1)$, whereas reliability with maximum redundancy is 0.99
r_2	is a parameter which relates the rate of increase in reliability to the amount of redundancy
W_R	is the weight, in pounds, which can be effectively allocated for equipment redundancies to increase reliability.

Therefore, the combined equation for dependability is

$$\text{Dependability} = \Big[P\{\text{Light threat}\} + \big(1 - P\{\text{Light threat}\}\big) \times \big(p_1 + p_2 W_S - p_3 W_S^2\big) \Big] (0.99) \big(1.0 - r_1 \exp\left[-r_2 W_R\right]\big) \tag{8}$$

<u>Capability Parameter For FOM (1)</u>

The capability parameter for FOM (1) (the probability of achieving a basic long range mission for a specified payload P_L) is the conditional probability of achieving a desired long range, given that the aircraft system is available and dependable.

The equation for the range (R) in still air of a turbojet aircraft in nautical miles is:

$$R = \frac{1}{c'} \left(\frac{\sqrt{C_L}}{C_D} \right) \sqrt{\frac{1181\, W_0}{\sigma S}} \left(1 - \sqrt{\frac{W_I}{W_0}} \right) \tag{9}$$

where

c'	is the consumption rate of the fuel in pounds of fuel per hour for each pound of thrust
C_L	is the lift coefficient
C_D	is the drag coefficient
W_0	is the initial weight of the plane, including fuel and cargo, in pounds
σ	is the ratio of the density of air at the cruising altitude to the mean atmospheric density at sea level
S	is the surface area of the wings in square feet

W_1 is the final weight of the plane in pounds, including cargo and remaining fuel, on landing. It is the sum $W_S + W_R + P_L + W_P + W_E$ where W_S and W_R are the weights allocated to the enhancement of survivability and reliability, as previously defined; P_L is the payload, or amount of cargo, in pounds; W_P is the amount of aircraft weight in pounds allocated to protection against threats, as previously defined; and W_E is the remaining, essential empty weight at the end of a mission.

Since the payload weight remains constant, the difference between the initial and final weights is the amount of fuel (F_R) used, namely:

$$F_R = W_0 - W_1 \tag{10}$$

Therefore,

$$\begin{aligned} W_0 &= W_1 + F_R \\ &= W_S + W_R + P_L + W_P + W_E + F_R \end{aligned}$$

and equation (9) may then be written as:

$$R = \frac{1}{c'}\left(\frac{\sqrt{C_L}}{C_D}\right)\sqrt{\frac{1181}{\sigma S}} \left(\sqrt{W_S + W_R + P_L + W_P + W_E + F_R} - \sqrt{W_S + W_R + P_L + W_P + W_E}\right) \tag{11}$$

The nominal range given by this equation and, hence, also the probability of achieving any given range, is maximized for a given initial weight, final weight, altitude, and fuel consumption rate when the critical drag ratio, $C_{DR} = \left(\sqrt{C_L}/C_D\right)$ is maximized. The drag coefficient (C_D) depends upon the lift coefficient approximately according to the relation:

$$C_D = C_{Df} + \left(C_L^2/\pi A_s e\right)$$

$$= C_{Df} + \left(C_L^2 S/\pi b^2 e\right) \qquad (12)$$

where:

C_{Df}	is the drag coefficient projected for a zero lift coefficient, and is due to skin friction
A_s	is the aspect ratio, which is the quotient of the square of the wing span divided by the wing surface area
b	is the wing span in feet
e	is Oswald's efficiency factor, which accounts for variation in drag due to the angle of attack and induced drag term. Under normal conditions, e is close to one.

The critical drag ratio (C_{DR}) is maximized when the aspect ratio A_s is equal to the following:

$$A_s = \frac{b^2}{S}$$

$$= \frac{3}{\pi} \frac{C_L^2}{e C_{Df}} \qquad (13)$$

When this equation is satisfied, the critical drag ratio (C_{DR}) reaches its maximum, namely,

$$C_{DR} = \frac{\sqrt{C_L}}{C_D}$$

$$= \left(\frac{\pi}{3} A_s e C_{Df}\right)^{1/4} \Big/ \left(\frac{4}{3} C_{Df}\right) \qquad (14)$$

Equation (9) also may be expressed in terms of the initial weight (W_0) of the aircraft, including cargo and fuel, as follows:

$$W_0 = \left(\sqrt{W_1} + \frac{Rc'}{C_{DR}} \sqrt{\frac{\sigma S}{1181}}\right)^2 \qquad (15)$$

Hence, a bare minimum of fuel (F_R) required, in pounds, under standard conditions is given by:

$$F_R = W_0 - W_1$$

$$= 2 \frac{Rc'}{C_{DR}} \sqrt{\frac{\sigma S W_1}{1181}} + \frac{R^2 c'^2}{C_{DR}^2} \frac{\sigma S}{1181} \qquad (16)$$

In the presence of a headwind of V_W knots and an average airspeed of V, equation (15) can be modified approximately as follows:

$$W_0 = \left(\sqrt{W_1} + \frac{Rc'}{C_{DR}\left(1 - V_W/V\right)} \sqrt{\frac{\sigma S}{1181}}\right)^2 \qquad (17)$$

The airspeed (V) is given by the following equation under the condition of maximum range:

$$V = \sqrt{295.25\ W/(\sigma C_L S)} \qquad (18)$$

and from equation (13),

$$V = 16.9 \sqrt{W/\left(\sigma b \sqrt{e C_{Df} S}\right)} \tag{19}$$

where the constant 295.25 is the conversion from statute miles to nautical miles of the constant in the Breguet range equation, and

b is the wing span in feet,

W is the weight of the aircraft at any time, and as an approximation is 1/2 the sum of W_0 and W_1, namely $W_S + W_R + P_L + W_P + W_E + 1/2\ F_R$

An assumption is made that wind velocity is normally distributed with a mean of zero velocity and a standard deviation of σ_{VW} knots. Therefore, the probability that the wind will be a headwind, and that the headwind component will exceed $3\sigma_{VW}$, is 0.135%. The amount of fuel (F_R) required to achieve a specified range (R') in spite of a $3\sigma_{VW}$ knot headwind is:

$$F_R = 2B\sqrt{W} + B^2 \tag{20}$$

where:

$$B = \frac{R'c'}{C_{DR}} \sqrt{\frac{\sigma S}{1181}} \Bigg/ 1 - \frac{3\sigma_{VW}}{16.9} \sqrt{\frac{\sigma b \sqrt{e C_{Df} S}}{W}}$$

Normally the required fuel capacity will be greater than F_R, such as $1.3\ F_R$, to account for contingencies other than headwinds.

The probability of achieving a specified range (R') under the assumption of normally distributed winds can be calculated according to the following steps:

- Calculate R according to equation (9).
- Determine the margin (R-R')/R.

- Multiply this margin by 16.9 $\sqrt{\dfrac{W}{\sigma b \sqrt{e C_{Df} S}}} \Big/ \sigma_{VW}$ to obtain the number of standard deviations for wind velocity.
- Convert the number of standard deviations to a probability by use of the normal distribution. For example, 3 standard deviations correspond to a probability of .99865.

The resulting probability is that of achieving the required range (R') subject to the achievement of safety and invulnerability goals. For this example, capability is considered to be the product of this probability and the parameters of safety and invulnerability. This may be written as:

$$\text{Capability} = \Phi\left[16.9\left(\sqrt{\frac{W}{\sigma b \sqrt{e C_{Df} S}}} \Big/ \sigma_{VW}\right)(R - R'/R)\right]$$

$$\times \text{ (Safety)} \times \text{ (Invulnerability)} \tag{21}$$

where

Φ is the cumulative probability function with

$$\Phi(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp\left[-x^2/2\right] dx \tag{22}$$

Safety is assumed to be 0.999

Range (R) is calculated according to equation (9)

Invulnerability is defined and determined as below

The invulnerability parameter is defined as the probability of flight survival under hostile threats. It is considered to be a function of the average intensity of enemy threats, the amount of aircraft protection against the threats, and the loss in total capability of the fleet resulting from the loss of aircraft because of their vulnerability to the threats. Invulnerability can be estimated as the fraction of actual fleet

capability in the presence of an enemy threat to fleet capability without this threat. For the purpose of this example, it is assumed to be of the form:

$$\text{Invulnerability} = \left(1 - \exp\left[-\lambda T\right]\right)/(\lambda T) \tag{23}$$

for:

T = the expected operating lifetime of the aircraft in the absence of an enemy threat

λ = the average lethality of all threats per hour of flight

The average lethality (λ) may be expressed mathematically as:

$$A_{CRS}\, L_1 \exp\left|-k_1 W_R/A_{CRS}\right| + 3600\, L_2 \exp\left|-k_2 W_P/A_{CRS}\right| + R_{AD}\, L_3 \exp\left|-k_3 W_S/A_{CRS}\right| \tag{24}$$

where:

A_{CRS} is the surface area of the aircraft in square feet

L_1 is the average number of lethal rounds per second of a light threat in the path of flight, under the assumption of no protection against this threat

W_P is the amount of protection and shielding afforded against the average threat, in pounds

W_R, W_S as previously defined

k_1 is the efficiency of the protection in combating a light threat, in units of square feet/pounds

L_2 is the average number of lethal rounds of a moderate threat per second

k_2 is the efficiency of the protection against the effects of a moderate threat, in units of square feet/pounds

L_3 is the average intensity of a heavy threat, in milliroentgens per hour

R_{AD} is the probability that the aircraft will be disabled during any time that it is unprotected from a heavy threat exposure

k_3 is the efficiency of the protection against a heavy threat, in units of square feet/pounds

Capability Parameter for FOM (2)

The transfer function of the capability parameter (C) for the FOM (2) measure (the average number of ton-miles of cargo delivered per aircraft per day over the lifetime of all aircraft in the fleet) is considered to be:

C = (Ton nautical miles per day, conditional upon aircraft availability and dependability) x (Safety)

Since ton-nautical mileage per hour is physically the product of flight velocity in nautical miles per hour (knots) and the number of tons of payload carried, and there are 24 potential flight hours per day under perfect availability, then:

C = (Payload in tons) x (Velocity in knots) x (Safety)

Using the relationship of equation (18), the approximation for W in equation (19), the weight of the aircraft at any time, and the conversion of pound payload to ton payload, then:

$$C = (0.012)\, P_L \sqrt{295.25\,(W_S + W_R + P_L + W_P + W_E + \tfrac{1}{2} F_R)/\sigma C_L S} \times (\text{Safety}) \qquad (25)$$

From equation (11), the fuel required (F_R) in equation (25) may be related approximately to other previously defined parameters and accountable factors of range as follows:

$$F_R = \frac{1}{2} X^2 + X \sqrt{W_S + W_R + P_L + W_P + W_E - \frac{1}{4} X^2} \qquad (26)$$

with

$$X = R'c' \left(\left|C_{Df}/C_L\right| + \left|C_L 3/\pi b^2 e\right|\right) \Big/ \sqrt{295.25/\sigma C_L S}$$

Figures of Merit

Each of the FOMs used in this example is assumed to be a product function of availability, dependability, and capability. FOM (1) is the probability of achieving a basic long range mission of R' nautical miles with a payload of P_L pounds. It is equal to the product:

$$\text{Availability} \times \text{Dependability} \times \text{Capability} \qquad (27)$$

where:

Availability is calculated according to equation (3)

Dependability is calculated according to equation (8)

Capability is calculated according to equation (21)

FOM (2) is the expected number of ton-nautical miles per day of cargo moved. It is also equal to the product:

$$\text{Availability} \times \text{Dependability} \times \text{Capability} \qquad (28)$$

where:

Availability and dependability are the same as for FOM (1)

Capability is calculated according to equation (25)

Cost Effectiveness Measure

The cost effectiveness measure is defined restrictively for illustration purposes, and is the ratio of FOM (2) to total operating costs per day (the cost effectiveness measure for FOM (1) is similar and, therefore, is not illustrated). For simplicity, the total costs are divided into three defined categories:

(1) Fixed costs per day (C_1), such as interest on aircraft production cost and depreciation which is independent of aircraft usage. Part of the

cost of producing an aircraft is the cost of making it readily maintainable. For purpose of trade-off, the relationship between maintainability and cost is assumed to be according to the following formula:

$$C_1 = \left(\frac{16,300}{\bar{M}_{mh}} + 26,000\right) \tag{29}$$

where the constants are sensitivity coefficients of the relationship between fixed acquisition cost per aircraft and maintenance man-hours per flight hour.

(2) Total maintenance costs per day (C_2), with

$$C_2 = \bar{M}_{mh}\, C_3\, \bar{F}_t \tag{30}$$

where:

C_3 is the average maintenance cost per manhour.

$\bar{M}_{mh}$ and $\bar{F}_t$ are as previously defined.

(3) The daily nonfixed costs (C_6), the portion of operating costs relating to aircraft usage, with

$$C_6 = \bar{F}_t\, C_4\, C_5 \tag{31}$$

where:

C_4 is the fuel and related costs per pound of fuel.

C_5 is the total fuel and related cost, with

$$C_5 = c' \left(\frac{C_{DF}}{C_L} + \frac{C_L S}{\pi b^2 e}\right)\left(W_S + W_R + P_L + W_P + W_E + \frac{1}{2} F_R\right) \tag{32}$$

Total cost (C_o) is then

$$
\begin{aligned}
C_o &= C_1 + C_2 + C_6 \\
&= \left[\frac{16,300}{\bar{M}_{mh}} + 20,000\right] + \bar{M}_{mh}\bar{F}_t C_3 + \bar{F}_t C_4 c' \left(\frac{C_{Df}}{C_L} + \frac{C_L S}{\pi b^2 e}\right) \\
&\cdot \left(W_S + W_R + P_L + W_P + W_E + \frac{1}{2}F_R\right) \qquad (33)
\end{aligned}
$$

Therefore, cost effectiveness (CE) is:

$$
\begin{aligned}
(CE) &= \text{FOM (2)/Total Cost} \\
&= ADC/C_o \qquad (34)
\end{aligned}
$$

where:

- A is given by equation (3)
- D is given by equation (8)
- C is given by equation (25)
- C_o is given by equation (33)

8. SYSTEM AND COST EFFECTIVENESS ANALYSIS

Three separate analyses will be required. These are:

- The determination of values for all free accountable factors and parameters such that FOM (1) is maximized.
- The determination of values for all free accountable factors and parameters such that FOM (2) is maximized.
- The determination of values for all free accountable factors and parameters such that (CE), the quotient of FOM (2) divided by the sum of all costs, is maximized.

At the outset, some direct optimizations may be made. For example, the system availability parameter for either FOM measure can be calculated directly from equation (3). Also, using equations (12) and (13), the optimum wing span can be

approximately derived based on the assumed values for the lift coefficient, the projected drag coefficient, and Oswald's efficiency factor. However, other values of accountable factors and parameters are not directly calculable and will require an iterative, composite analysis to determine thei best combination of values so that the dependent FOM or CE measure is maximized.

The results of the three separate analyses to establish the optimum values for the involved free accountable factors and parameters are summarized in Tables A-5 and A-6. Additionally, the numerical values for the sensitivity of the critical parameters to changes in contributing parameters and accountable factors are given in Table A-7. This table represents an updating of Table A-4 in paragraph 6, and is obtained by differentiating the equations (transfer functions) given in paragraph 7.

TABLE A-5 CALCULATED VALUES FOR FOM (1)

Figure of Merit: The probability of achieving a basic long range mission with a specified payload.

	Accountable Factor/ Parameter Value
Availability (A)	0.714
Flight-hours per day ($\tilde{F}_t$)	17.1 hours/day
Dependability (D)	0.939
Reliability	0.988
Survivability	0.950
Capability (C)	0.996
Final weight (W_1)	556,500 pounds
Wing span (b)	215 feet
Drag coefficient (C_D)	0.04
Velocity of flight for maximum range (V)	511 knots
Range in still air (R)	4,570 nautical miles
Weight allocated to reliability (W_R)	3,800 pounds
Weight allocated to survivability (W_S)	700 pounds
Allocation of payload to protection against threats (W_P)	2,000 pounds
FOM (1)	0.668

TABLE A-6 CALCULATED VALUES FOR FOM (2)

Figure of Merit: The average number of ton-miles of cargo delivered per aircraft per day over the lifetime of all aircraft in the fleet.

	Accountable Factor/ Parameter Value	
	For Max. FOM (with fixed $\overline{M}_{mh}$)	For Max. CE (without fixed $\overline{M}_{mh}$)
Availability (A)	0.714	0.775
Flight hours per day (F_t)	17.1	18.6 hours/day
Actual direct maintenance manhours per aircraft flight hour ($\overline{M}_{mh}$)	4.0	2.4
Dependability (D)	0.936	0.936
Reliability	0.986	0.986
Survivability	0.949	0.949
Capability (C)	1,517,000	1,517,000 ton-miles/ day
Wing span (b)	215	215 feet
Drag coefficient (C_D)	0.04	0.04
Payload (P_L)	248,000	248,000 pounds
Weight allocated for reliability (W_R)	1,600	1,600 pounds
Weight allocated to survivability (W_S)	0	0 pounds
Total Cost (C_Ω)	\$99,600	\$102,000/day
Fixed daily cost (C_1)	\$24,100	\$ 26,700/day
Maintenance cost (C_2)	\$ 1,710)	\$ 1,710/day
Fuel and related cost (C_5)	\$73,800	\$ 73,800/day
FOM (2)	1,014,000	1,100,000 ton-miles/ day
Cost Effectiveness	10.2	10.8 ton-miles/ dollar

TABLE A-7 CALCULATED SENSITIVITY RELATIONSHIPS

1 pound change in payload = 4.0 ton-nautical miles per day
0.001 unit of survivability = 1000 ton-nautical miles per day
1 pound of protection = 1.5×10^{-7} unit of unvulnerability
1 pound of protection = 1.0 pound of payload
1 foot cruising altitude = 15 ton-nautical miles per day
0.001 unit fuel consumption rate coefficient = -14 nautical miles range
1 foot cruising altitude = 0.068 nautical mile range
280 pounds payload = -1 nautical mile range
0.001 unit lift coefficient = 4.5 nautical miles range
0.001 unit drag coefficient = -180 nautical miles range
0.001 unit fuel consumption rate coefficient = $231. of fuel cost per day
1 pound payload = $0.059 of fuel cost per day
0.001 unit lift coefficient = $73.80 of fuel cost per day
0.001 unit drag coefficient due to skin friction = $2,960. of fuel cost per day

Comments on FOM (1) Analysis Results

The range parameter is the principal system parameter contributing to the FOM (1) measure. The established goal for this parameter to guide conceptual studies was a minimum of 4,000 nautical miles. A minimum range capability in still air of 4,570 nautical miles was analytically determined to be required and obtainable for the example transport concept. This higher design range value compensates for expected headwind conditions. Further, the probability of achieving the FOM was determined to be 0.668, short of the wartime mission goal of 0.70 by 0.032. Many options are available to overcome this deficiency. For example, operational tactics can be modified to provide tactical aircraft support to neutralize anticipated enemy threats, thereby increasing the transport's inherent invulnerability, and correspondingly, its FOM measure.

The estimate of 0.714 for the availability parameter is based upon a measure which considers the potential maximum utilization of each transport for a 24 hour operating day. This primarily addresses an emergency, wartime plan for continuous usage. For peacetime or limited war missions where usage demands are not as severe, a lesser amount of maintenance is anticipated. Consequently, a higher availability value can be expected (e.g., if the transport usage baseline is an average of 12 hours per day, transport availability will be close to one). Coupled with a companion, anticipated increase in system survivability due to infrequently expected enemy threats for the peacetime or limited war mission, the goal of 0.98 for the FOM (1) for this mission is reasonably attainable.

Comments on FOM (2) Analysis Results

Two values were obtained for the FOM (2) measure of the number of ton-miles of cargo moved per day. One was for a maximum system effectiveness criterion without the presence of major cost alternatives. The other was for an optimum cost effectiveness criterion.

In each case, the value obtained was approximately three times the specified goal of 340,000 ton-miles because the analysis was addressed to the most severe operational demands. These demands are:

- Each aircraft is to be fully utilized each day except for that portion of a day when it is undergoing maintenance.
- Each aircraft is to carry a full load of cargo on each flight to and from a specified destination.

Both of these operational demands for full utilization of each aircraft occur only in emergency and sustained wartime situations. Even in such instances, it is still not anticipated that each transport will fly a return trip with a full cargo load. Thus, when considering a more realistic mission of a transport to be utilized an average of 12 hours a day and to fly empty one-third of its total flight time (with the other two-thirds of the time fully loaded), then the transport system will be capable of moving approximately 350,000 ton-miles per day, exceeding the specified goal of 340,000.

The goal of 250,000 pounds for payload is missed by 0.8%. Design or operational alternatives are available to achieve the goal, such as flying at a higher cruise altitude or in-flight refueling provisions so that less fuel will be required to be carried.

Appendix B
SYNTHESIS AND ANALYSIS METHODS FOR DETERMINING TRANSFER FUNCTIONS, OUTPUTS, AND INPUTS

Introduction

This appendix summarizes the synthesis and analysis procedures to be used to establish transfer functions and to evaluate measures of:

- Figures of Merit (FOMs)
- Effectiveness parameters of availability, dependability, and capability
- System parameters integrated by the effectiveness parameters
- First-level accountable factors (design variables)

Depending on the level to which the synthesis and analysis are being addressed, each of these measures may be evaluated as an output of transfer functions for defined inputs. Output-input relationships may be as follows:

Output	Input
• FOM	Effectiveness parameters, system parameters, or first-level accountable factors
• Effectiveness parameters	System parameters or first-level accountable factors
• System parameters	First-level accountable factors
• First-level accountable factors	Lower-level accountable factors

Part B1 – Synthesis Method

The synthesis method can be applied to determine optimum transfer functions, given knowledge only of the inputs and required outputs. Additionally, this method will allow for the development of a block diagram for the system having these transfer functions. The result is that an optimum system can be selected from a set of possible systems without analyzing each candidate system in the set. The synthesis method is inherently more difficult that the analysis methods described in Parts B2 and B3 of this appendix, which can be used to find the optimum input or output values, given the set of transfer functions. Further, there is a possibility that the set of transfer functions may not exist in a form suitable for analytical use. There also is the fundamental design problem of finding a physical representation for the system with the optimum set of transfer functions.

The synthesis method is simplified if the system can be linearized and the time-varying elements are not complex. Where complexity exists, the method is useful to obtain approximate optimum systems.

A commonly occurring transfer function applicable to delayed response is one which is in the form of the superposition (convolution) integral. This integral is:

$$y(t) = \int_0^t g(t, \tau)\, x(\tau)\, d\tau, \tag{1}$$

where

- t is time,
- $y(t)$ is an analytically obtained output function of time,
- $g(t, \tau)$ is the impulse response transfer function relating $y(t)$ to $x(\tau)$,
- $x(\tau)$ is an input function of τ, which in turn is a variable of integration having the dimension of time.

Given this superposition integral relationship, a known input function $x(\tau)$, and a desired (known) output function $\mu(t)$, a procedure is available for determining the transfer function $g(t, \tau)$ which will result in an actual output function $y(t)$

as closely as possible to the desired output function $\mu(t)$. This procedure is as follows:

(1) Establish a criterion for determining the closeness of fit of $y(t)$ to $\mu(t)$, such as developing a system that will produce the smallest error $(\mu(t) - y(t))$ in a mean-squared sense. Mathematically this criterion can be a minimum expected value E expressed as:

$$E\left(\left|\mu(t) - y(t)\right|^2\right) = \text{Minimum}$$

Another criterion is that the time-averaged mean-square error is a minimum.

(2) Define an autocorrelation function $\phi_{xx}(t, \tau)$ and a cross-correlation function $\phi_{\mu x}(t, \tau)$ which represent the expected value of $x(t)\, x(\tau)$ and $\mu(t)\, x(\tau)$, respectively. In most applications, these functions can be sufficiently approximated by linear combinations of functions $a_q(t)$, $b_q(t)$, and $c_q(t)$ such that:

$$\phi_{xx}(t, \tau) = \sum_{q=1}^{Q} a_q(t)\, b_q(\tau) \quad \text{if} \quad \tau \leq t$$

$$\phi_{xx}(t, \tau) = \sum_{q=1}^{Q} a_q(\tau)\, b_q(t) \quad \text{if} \quad \tau > t$$

$$\phi_{\mu x}(t, \tau) = \sum_{q=1}^{Q} c_q(t)\, b_q(\tau)$$

From equation (1), establish the following integral relations:

$$\phi_{\mu x}(t, \tau) = \int_0^t g(t, \sigma)\, \phi_{xx}(\tau, \sigma)\, d\sigma$$

where σ is a variable of integration.

Express the equations for $\phi_{xx}(t, \tau)$ and $\phi_{\mu x}(t, \tau)$ in vector notation as follows:

$$\phi_{xx}(t, \tau) = \underline{a}(t) \cdot \underline{b}(\tau) \qquad \text{if} \quad \tau \leq t$$

$$= \underline{a}(\tau) \cdot \underline{b}(t) \qquad \text{if} \quad \tau > t$$

$$\phi_{\mu x}(t, \tau) = \underline{c}(t) \cdot \underline{b}(\tau)$$

where $\underline{a}(t)$ is the vector $\left[a_1(t), \ldots, a_Q(t)\right]$, and the vectors $\underline{b}(t)$ and $\underline{c}(t)$ are similarly defined as Q-th order vectors.

(3) Find Q-th order vectors $\underline{g}(t)$ and $\underline{\gamma}(\tau)$ such that:

$$g(t,\tau) = \underline{g}(t) \cdot \underline{\gamma}(\tau) \; u(t - \tau)$$

with

$$u(t - \tau) = 1 \quad \text{if} \quad t > \tau$$

$$= 0 \quad \text{if} \quad t \leq \tau$$

This is accomplished by the following:

(a) Define the function I_{qp}, where:

$$I_{qp}(t) = \int_0^t a_q(\tau) \; \gamma_p(\tau) \, d\tau$$

(b) Define the function $w(t - \tau)$, where:

$$w(t - \tau) = \left|\underline{a}(t) \, \underline{b}(\tau) - \underline{a}(\tau) \, \underline{b}(t)\right|$$

This function, in most applications, depends on $(t - \tau)$ alone.

(c) Define the Laplace transform $W(x)$ and $\underline{B}(s)$ of $w(t)$ and $\underline{b}(t)$, respectively, where:

$$W(s) = \int_0^\infty e^{-st} \, w(t) \, dt$$

$$\underline{B}(s) = \int_0^{\infty} e^{-st}\, \underline{b}(t)\, dt$$

(d) Define the vector function $\underline{\Gamma}(s)$, where

$$\underline{\Gamma}(s) = \underline{B}(s)/W(s)$$

(e) Determine the vector function $\underline{\gamma}(\tau)$, which is the inverse Laplace transform of $\underline{\Gamma}(s)$, where:

$$\underline{\gamma}(\tau) = \frac{1}{2\pi i} \int_{a-i\infty}^{a+i\infty} e^{s\tau}\, \underline{\Gamma}(s)\, ds$$

with:

$i = \sqrt{-1}$, and a is a real number located to the right of all singularities of $\underline{\Gamma}(s)$ in the complex plane.

(f) Determine the functions $g_1(t), \ldots, g_Q(t)$, which are the elements of the vector $\underline{g}(t)$, by solving a system of equations. In matrix form, these equations are

$$\begin{bmatrix} (1+I_{11}) & I_{12} & \cdots & I_{1Q} \\ I_{21} & (1+I_{22}) & \cdots & I_{2Q} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ I_{Q1} & I_{Q2} & \cdots & (1+I_{QQ}) \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \\ \cdot \\ \cdot \\ \cdot \\ g_Q \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \cdot \\ \cdot \\ \cdot \\ c_Q \end{bmatrix}$$

where the symbol (t) has been omitted for all I, g, and c elements for brevity.

(4) Determine the impulse response transfer function $g(t, \tau)$ by evaluating the following equations:

$$g(t, \tau) = \left[\underline{g}(t) \cdot \underline{\gamma}(\tau)\right] u(t-\tau) + \sum_k h_k(t)\, \delta^{(k)}(t-\tau),$$

where

$h_k(t)$ may be chosen in an arbitrary manner to simplify g, and

$\delta^{(k)}(t-\tau)$ represents the k-th derivative of the translated unit impulse function.

By setting each $h_k(t)$ to zero, one particular solution for $g(t, \tau)$ can be obtained.

(5) Establish an optimum block diagram representation of the system configuration based on the determined function $g(t, \tau)$.

Part B2 — Analysis Method I

The analysis method I can be applied to determine an optimum output $y(t)$, given knowledge of the input function $x(\tau)$ and the transfer function $g(t, \tau)$. The general form for a time-delayed response function is the superposition integral of equation (1), which is:

$$y(t) = \int_0^t g(t, \tau)\, x(\tau)\, d\tau$$

If $g(t, \tau)$ is of the form where it is a product of functions of single variables, then $g(t, \tau)$ can be expressed as:

$$g(t, \tau) = a(\tau)\, g(t - \tau).$$

Equation (1) then will take the following form:

$$y(t) = \int_0^t x(\tau)\, a(\tau)\, g(t - \tau)\, d\tau, \tag{2}$$

where

$a(\tau)$ is a time variable gain element and

$g(t - \tau)$ is a time-delay function (impulse response transfer function)

Figure B-1 is the analog representation of equation (2).

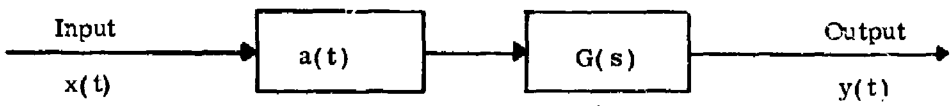


Figure B-1

Direct computation of the optimum output $y(t)$ using equation (2) is difficult, especially if the impulse response transfer function $g(t - \tau)$ is determined empirically, or as the result of analog computations. An alternate procedure is to formulate the adjoint to equation (2) and Figure B-1. This adjoint is mathematically equivalent and is:

$$y(t) = \int_0^t x(t - \tau)\, a(t - \tau)\, g(\tau)\, d\tau \qquad (3)$$

This equation is more convenient to evaluate than the original equation (2) in applications where all that is known of the input $x(t - \tau)$ is that it is a random variable with a particular distribution. Figure B-2 is the analog representation of this adjoint equation.

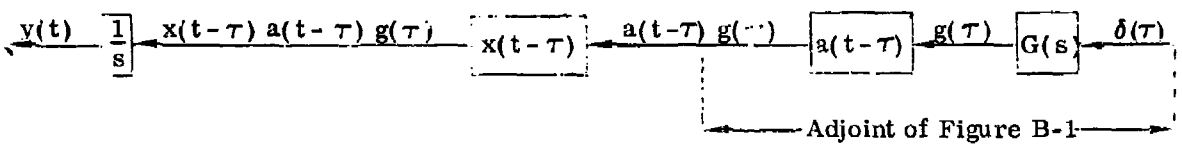


Figure B-2

The chief differences between the original system and its adjoint system are that (1) in the analog representation, the time function is reversed, and (2) the operators $G(s)$ and $a(t)$ are applied in reverse order. The advantage of the adjoint system is that the operator G is applied to the input first, and the result then applied to an ensemble of inputs $x(t - \tau)$.

For example, the input ensemble $x(t - \tau)$ may be random with mean $m(t - \tau)$ and standard deviation $\sigma(t - \tau)$. If $m_1(t)$ and $\sigma_1(t)$ are the mean and standard deviations, respectively, of the output function $y(t)$, then the adjoint equations corresponding to equation (3) are:

$$m_1 = \int_0^t m(t - \tau)\, a(t - \tau)\, g(\tau)\, d\tau$$

$$\sigma_1 = \int_0^t \sigma(t - \tau)\, a(t - \tau)\, g(\tau)\, d\tau .$$

Figure B-3 is the adjoint analog block representation for this set of equations.

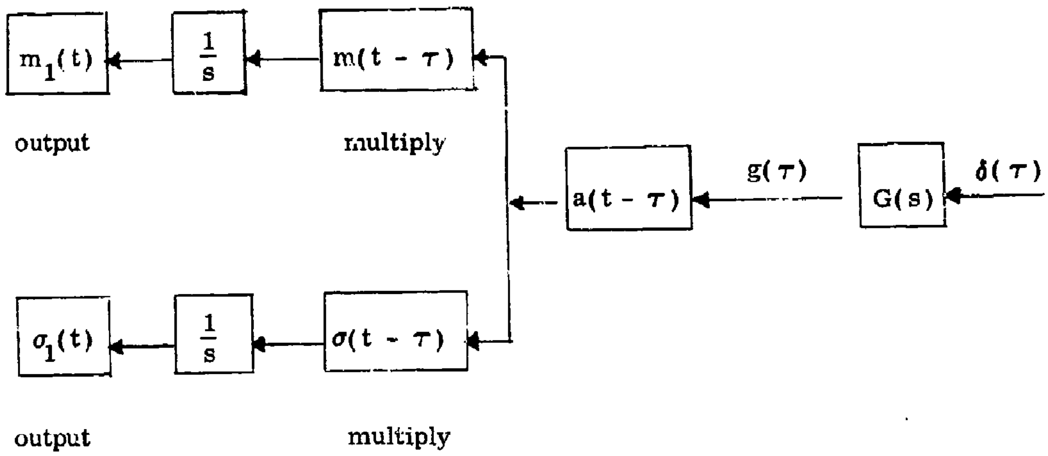


Figure B-3

The adjoint representation saves computation labor in that the common operator $G(s)$ is applied before the branching of the network into multiplication operations. The multipliers of the example network are the mean input $m(t - \tau)$ and the standard deviation $\sigma(t - \tau)$ of the input.

Part B3 – Analysis Method II

The analysis method II can be used to address the problem of determining input $x(\tau)$ if the desired values of a time varying output function $y(t)$ and the transfer function $g(t,\tau)$ are known, where $y(t)$ can be expressed as:

$$y(t) = \int_0^t g(t,\tau)\, x(\tau)\, d\tau \tag{4}$$

In many applications, the output is a time varying response function dependent upon an input or input ensemble, and expressible as:

$$y(t) = a\, e^{-ct} + \int_0^t e^{-c(t-\tau)}\, x(\tau)\, d\tau,$$

where

a is the value of y when time (t) is zero, and

c is a constant which indicates how fast the output response is damped.

The solution for the optimum input function involves the use of Laplace transforms, and is:

$$x(t) = \frac{d\mu(t)}{dt} + \mu(0^+)\,\delta(t) + c\mu(t) - a\delta(t)$$

where

$\mu(0^+)$ is the value of μ when t is zero. If there is a jump in μ at $t = 0$, $\mu(0^+)$ means the value of μ immediately after this jump.

$\delta(t)$ is an impulse function with a value of $1/\epsilon$ if t is between 0 and ϵ, and is otherwise 0, where ϵ is a small postive number.

A more general problem which can be solved by this method is to determine the input function $x(\tau)$ and the output function $y(t)$ such that equation (4) and the following differential equation are satisfied

$$\frac{dy(t)}{dt} = b(t)\,y(t) + c(t)\,x(t),$$

where $b(t)$ and $c(t)$ are specified functions of time.

Subject to these requirements, the input and output functions should be as close as possible to stipulated desired input and output functions $\gamma(\xi)$ and $\mu(\xi)$, respectively. Mathematically, this implies minimizing the following function J:

$$J = \int_0^T \left\{ \phi(\xi)[\mu(\xi) - y(\xi)]^2 + \psi(\xi)[\gamma(\xi) - x(\xi)]^2 \right\} d\xi,$$

where

$\phi(\xi)$ and $\psi(\xi)$ are weighting functions relating the relative importance of matching output and input functions, respectively, to the desired values of these functions, and

T is the length of the time interval during which the input and output functions are required for the system. Time t is 0 and T at the beginning and end, respectively, of this interval.

The procedure for determining the required input function $x(t)$ and output function $y(t)$ is as follows:

(1) Define functions $k_1(t)$ and $k_2(t)$ such that the following equations are satisfied:

$$k_1(T) = k_2(T) = 0$$

$$\frac{dk_1}{dt} = 2\phi\mu - bk_1 - 2ck_2\gamma + \frac{c^2 k_1 k_2}{\psi}$$

$$\frac{dk_2}{dt} = -\phi - 2bk_2 + \frac{c^2 k_2^2}{\psi},$$

where k_1 means $k_1(t)$, k_2 means $k_2(t)$, ϕ means $\phi(t)$, etc. In order to determine k_1 and k_2, the last two equations must be integrated backward from T to 0.

(2) Determine input $x(t)$ and output $y(t)$ by integrating forward from 0 to T to solve the following equations simultaneously:

$$x = \gamma - \frac{c}{2\psi}\left[k_1 + 2k_2 y\right];$$

$$\frac{dy}{dt} = by + cx,$$

where all quantities are function of time t.

Appendix C
COMBINATION OF SENSITIVITY FUNCTIONS

This appendix describes the detail procedure for combining sensitivity functions relating accountable factors to the effectiveness parameters of availability, dependability, and capability with sensitivity functions that relate these effectiveness parameters to a Figure of Merit. The procedure is equally applicable to the combination of sensitivity functions associated with more than two design levels.

The changes $(\Delta_i A)$, $(\Delta_j D)$, and $(\Delta_k C)$ in the system effectiveness parameters of availability (A), dependability (D), and capability (C), respectively, due to changes in accountable factors α_i, β_j, and γ_k from their nominal values by amounts $(\Delta\alpha_i)$, $(\Delta\beta_j)$, and $(\Delta\gamma_k)$, respectively, can be represented by sensitivity functions of the following types:

$$\Delta_i A = a_i(\Delta\alpha_i) + \left(\text{terms involving higher powers of } (\Delta\alpha_i)\right);$$

$$\Delta_j D = d_j(\Delta\beta_j) + \left(\text{terms involving higher powers of } (\Delta\beta_j)\right);$$

$$\Delta_k C = c_k(\Delta\gamma_k) + \left(\text{terms involving higher powers of } (\Delta\gamma_k)\right);$$

where

α_i is the i-th accountable factor influencing the availability parameter;

β_j is the j-th accountable factor influencing the dependability parameter;

γ_k is the k-th accountable factor influencing the capability parameter;

and

a_i, d_j, and c_k are partial derivatives of the availability, dependability, and capability parameters with respect to their accountable factors. These partial derivatives describe the slope representing the ratio of the changes in availability, dependability, and capability to the changes in their respective accountable factors α_i, β_j, and γ_k.

If the same accountable factor influences more than one of the system effectiveness parameters of availability, dependability, and capability, it will appear in more than one of the three accountable factor sets of α, β, and γ.

The total changes (ΔA), (ΔD), and (ΔC) in a system effectiveness parameter of availability, dependability, or capability due to the changes in all of its accountable factors can be considered as the sum of changes arising from individual changes in the accountable factors, plus nonlinear terms to relate the interactive effect of changes in two or more accountable factors. Hence,

$$\Delta A = a_1(\Delta\alpha_1) + a_2(\Delta\alpha_2) + \cdots + a_I(\Delta\alpha_I) + \left(\text{terms involving higher powers of the } (\Delta\alpha)\text{'s}\right);$$

$$\Delta D = d_1(\Delta\beta_1) + d_2(\Delta\beta_2) + \cdots + d_J(\Delta\beta_J) + \left(\text{terms involving higher powers of the } (\Delta\beta)\text{'s}\right);$$

$$\Delta C = c_1(\Delta\gamma_1) + c_2(\Delta\gamma_2) + \cdots + c_K(\Delta\gamma_K) + \left(\text{terms involving higher powers of the } (\Delta\gamma)\text{'s}\right);$$

where

I, J, and K are the number of accountable factors which influence availability, dependability, and capability, respectively.

The top-level effectiveness function also may be approximated by sensitivity functions that will relate the change ΔE in the Figure of Merit from its nominal value to the changes ΔA, ΔD, and ΔC in availability, dependability, and capability, respectively, from their nominal values. The combined effect of all these sensitivity functions can be expressed by an equation of the following type:

$$\Delta E = e_1(\Delta A) + e_2(\Delta D) + e_3(\Delta C) + \left(\text{terms involving higher powers of } \Delta A,\ \Delta D, \text{ and } \Delta C\right),$$

where

e_1, e_2, and e_3 are the slopes representing the ratios of the change in the Figure of Merit caused by a change in availability, dependability, and capability to the amount of change in availability, dependability, and capability, respectively.

The formulas may be combined mathematically to yield a single formula for the sum of the sensitivity functions. This formula will relate the changes in accountable factors from their nominal values to changes in the Figure of Merit from its nominal value, namely,

$$\begin{aligned}\Delta E = {} & a_1 e_1(\Delta\alpha_1) + a_2 e_1(\Delta\alpha_2) + \cdots + a_I e_1(\Delta\alpha_I) \\ & + d_1 e_2(\Delta\beta_1) + d_2 e_2(\Delta\beta_2) + \cdots + d_J e_2(\Delta\beta_J) \\ & + c_1 e_3(\Delta\gamma_1) + c_2 e_3(\Delta\gamma_2) + \cdots + c_K e_3(\Delta\gamma_K) \\ & + \big(\text{terms involving higher powers of the } (\Delta\alpha)\text{'s}, \\ & (\Delta\beta)\text{'s, and the } (\Delta\gamma)\text{'s}\big).\end{aligned}$$

Additionally, the formula may be used to determine the combination of changes in one or more of the accountable factors that would result in the largest increase in the Figure of Merit without violating any design restrictions or requirements which may be placed upon the accountable factors.

Appendix D
APPORTIONMENT PROCEDURES

Introduction

This appendix summarizes the procedure to be used to implement selected methods for apportioning system effectiveness-related measures of:

- Figures of Merit (FOMs)
- Effectiveness parameters of availability, dependability, and capability
- System parameters integrated by the effectiveness parameters
- First-level accountable factors (design variables)

Depending on the level to which the effectiveness apportionment analysis is being addressed, each of these measures may be evaluated as outputs of transfer functions for defined inputs. Output-input relationships may be as follows:

Output	Input
• FOM	Effectiveness parameters, system parameters, or first-level accountable factors
• Effectiveness parameters	System parameters or first-level accountable factors
• System parameters	First-level accountable factors
• First-level accountable factors	Lower-level accountable factors

The apportionment analysis process basically involves the determination of the best values for the input ensemble which will optimize the output being analyzed. Upon establishment of the optimum output value, the corresponding values of the inputs associated with this optimum are the desired apportioned values.

Methods for optimizing an output measure subject to mission or system performance constraints include the (1) Lagrangian method, (2) Lagrangian method with priority lists, (3) dynamic programming, (4) direct comparison (direct search), (5) linear

programming, (6) gradient projection, and (7) calculus of variations. A general mathematical overview of methods (1), (3), (5), and (7) is included in the System/Cost Effectiveness Notebook, RADC-TR-68-352, dated April 1969. This appendix expands on the application procedure for methods (1) and (3), and adds the procedures for methods (2), (4), and (6), the Lagrangian method with priority lists, the direct comparison (direct search) method, and the gradient projection method of apportionment, respectively. The procedures for (5) linear programming and (7) calculus of variations are commonly used in system analyses. Based on this fact, the procedures for these two methods covered in the Notebook are in sufficient detail for most applications and are not expanded further in this appendix.

Prior to the implementation of any of the methods described herein, the following must be determined:

- The nature of the output to be maximized or minimized
- The transfer functions relating the output to the input variables
- The constraints placed upon outputs and/or specific input variables.

If specific input and/or output variables are constrained by limiting values due to considerations such as resources available, mission performance and operational demands, and system compatibility requirements, then it is necessary that planned design values for these variables be within the existing limitations. This restriction on the values of the variables may be expressed mathematically as:

$$f_k \leq C_k, \quad \text{for } k = 1, \ldots, c \tag{1}$$

or

$$f_k \geq C_k$$

where

c is the number of constraints

f_k is the planned design value of the k-th constrained variable; and

C is the upper or lower limit on the k-th constrained variable.

To simplify the procedural description for the various apportionment methods, only constraints of the form $f_k \leq C_k$ shall be considered to be present for the system. However, by replacing f_k and C_k by $-f_k$ and $-C_k$ respectively, the procedures may be extended to constraints of the form $f_k \geq C_k$. Additionally, an output value, as referred to in this appendix, will be used to denote either its true value or its value resulting from a change of sign, according to whether the true output is to be maximized or minimized. The output then can be uniformly interpreted as a function to be maximized. Also, the terms input and output are used in the general sense that they may represent a single variable or an ensemble of variables.

The Lagrangian Method

A general method for establishing an input that will optimize an output involves the use of numbers referred to as Lagrange multipliers. The procedure for using such a method consists of the following steps:

(1) For an output variable E, formulate a modified output variable by subtracting from it terms relating to the constraints. This modified output variable is the variable to be optimized and is given by the following equation:

$$E - \sum_{k=1}^{c} \lambda_k (f_k - C_k) \qquad (2)$$

The quantities λ_k are the Lagrange multipliers. Physically, they represent penalties for violation of the constraints. These penalties are charged against the output variable. The values for the Lagrange multipliers are chosen so that when the modified output variable is optimized, none of the constraints is violated.

(2) Perform a partial differentiation of the modified output variable with respect to each of the input variables and equate to zero. Each of the resulting partial derivatives will be zero at the optimum solution. As a consequence of this operation, a set of equations is obtained, with the number of equations in the set corresponding to the number of input

variables. Thus, if there are N variables α, then the following N equations will be formulated:

$$\frac{\partial E}{\partial \alpha_i} - \sum_{k=1}^{c} k \frac{\partial f_k}{\partial \alpha_i} = 0, \text{ for } i = 1, \ldots, N \tag{3}$$

This set of N equations, plus the c constraint relationships are represented by the formula $f_k \leq C_k$, will constitute (N + c) equations with a total of (N + c) unknowns. These unknowns will consist of N input variables and c Lagrange multipliers.

(3) Solve the (N + c) equations. One solution method is to solve the first N equations for the input variables by Newton's iterative method, with fixed values, close to zero, for the Lagrange multipliers. If any of the constraints is violated, the values of the corresponding Lagrange multipliers should be changed, and the solution redetermined. Repeat this process until each multiplier approaches the lowest value such that none of the constraints are violated.

The procedure for using Newton's method in solving the first N equations for the values of the inputs α, with fixed values of the Lagrange multipliers λ, is as follows:

(a) Make an initial estimate of the input values α

(b) Calculate for these inputs all the quantities contained in the following system of linear equations, except the unknowns Δ :

$$\sum_{k=1}^{N} \left(\partial g_j / \partial \alpha_i \right) \Delta_i = -g_j, \text{ for } j = 1, \ldots, N,$$

where g_j is defined by

$$g_j = \frac{\partial E}{\partial \alpha_j} - \sum_{k=1}^{N} \lambda_k \frac{\partial f_k}{\partial \alpha_j} \tag{4}$$

(c) Solve for the unknowns Δ_i

(d) Add Δ_i to α_i for all i from 1 to N

(e) Repeat the process from Step (b) until each input value α_i approaches the optimum value sought.

A method such as Newton's method is likely to require the use of a computer. If several input variables interactively influence the output, but such interactions are insignificant, a simplified procedure involving the use of priority lists will converge and can be used.

Lagrangian Method With Priority Lists

With this method, the value of only one input variable is improved at each step. The word "priority" connotes that for each step the input variables are ranked according to the magnitude of improvement in the output function resulting from a change in the value of an individual input variable. At each step, only the value of the input variable with the highest ranking is improved.

A Lagrange multipler is the ratio of the rate of change of the output function to the rate of change of the constraint function. Alternately, it may be interpreted as representing the ratio of the rate at which the output function is optimized to the rate that the slack is taken up in the constraint as the input value is changed. In general, this interpretation of Lagrangian multipliers applies to the case where there are any number of constraints. A slack is the margin by which the constraint is not violated. For example, if the constraint is $f_1 \leq C_1$, then the slack is $C_1 - f_1$.

For the case where only one constraint exists, the Lagrange multiplier may be denoted as λ, and be expressed as:

$$\lambda_1 = \lambda_{(1)i}$$

$$= \frac{\partial E}{\partial \alpha_i} / \frac{\partial f_1}{\partial \alpha_i} \tag{5}$$

The values $\lambda_{(1)i}$, for $i = 1$ to N, may be different from each other for the steps of the iterative solution, but will converge to a common value λ_1 at the last iteration. Equation (5) is the one-constraint equivalent of equation (3).

For the case of one constraint the procedure for optimization is as follows:

(1) Choose a tentative value for each input variable so that none of the constraints are violated. Calculate the derivatives of the output function E and the constraint function f_1 with respect to each input variable α_i. Compute the ratios. These ratios are priority numbers designated $\lambda_{(1)i}$ according to equation (5). One of these ratios is computed for each input variable α_i. Arrange the input variables in a priority list by descending order of their corresponding priority numbers.

(2) Increase (or decrease) the value of the first listed input that will improve the output until either the output is optimized for that variable or any constraint depending on that variable is reached. It will be necessary to recompute the output and the constraint as the input is varied.

(3) Recalculate the priority numbers $\lambda_{(1)i}$ and reorder the list if necessary.

(4) Back away from the constraint by adjusting the value of the last input on the priority list in such a way as to introduce slack into the constraint inequalities, even if this represents a decrease in the output function. The amount of this adjustment should be small or moderate, such as a unit step.

(5) Iterate these steps until all the priority numbers are as close together as possible. For a continuous method, they may theoretically be made equal.

The resulting values of the input variables constitute an optimum solution. If there are more than one constraint, the method may be applied by considering one constraint at a time and avoiding those input values which may cause any of the constraints to be violated. If this procedure is unmanageable, an alternative is to treat all constraints simultaneously. For each input variable and at each step, this is accomplished by constructing a priority number relating to all constraints, and proceeding as in the case of one constraint. Such a priority number, for the i-th input variable α_i, is generated by the following process:

(1) For each constraint, such as the k-th constraint, multiply each priority number $\lambda_{(k)i}$ by the slack in the k-th constraint, and call the result $\lambda^*_{(k)i}$.

(2) For each i-th input variable, determine the value of k for which $\lambda^*_{(k)i}$ is the smallest. This value is the priority number based upon all constraints to use for the i-th input variable.

In order for the Lagrangian method with priority lists to provide an optimum solution efficiently, the partial derivative of both the constraint and output functions with respect to each of the inputs α_i, namely $\partial f/\partial\alpha_i$ and $\partial E/\partial\alpha_i$, should be functions principally of only α_i and independent of other inputs. A simple transformation, such as a logarithmic transformation, may be required to provide the independence, especially when the output function is a product of inputs. If the partial derivatives are significantly dependent on the other inputs, convergence of the Lagrangian method with priority lists to an optimum solution will be slow. In such situations, the use of the classical Lagrangian method will be more efficient, with the resulting equations solved by Newton's method or a comparable method.

Dynamic Programming Method

The dynamic programming method involves the optimization of one input at a time for a multi-input situation. This method is based on the principle that if the value chosen for a specific input is optimized, then the values for the remaining inputs to be chosen to optimize the output are subject to the decision made on the first input.

Problems most readily solved by the method of dynamic programming are those which can be represented in a form in which the contribution of each input to the output E is additive, namely

$$E = g_1(\alpha_1) + g_2(\alpha_2) + \ldots g_N(\alpha_N) \tag{6}$$

and where the constraint is a linear combination of contributing inputs α. If there are M number of inputs out of N inputs α which contribute to such a constraint, then the constraint may be mathematically described as follows:

$$C \geq \sum_{i=1}^{M} s_i \, \alpha_i, \quad \alpha_i \geq 0 \text{ for } i = 1, 2, 3, \ldots, M.$$

In order to implement the dynamic programming method, a series of functions of an arbitrary variable x, for x between 0 and C, is defined:

$$f_1(x) = g_1(x/s_1);$$

$$f_i(x) = \underset{0 \leq x_i \leq x}{\text{maximum}} \left[g_i(x_i/s_i) + f_{i-1}(x - x_i) \right], \quad i = 2, 3, 4, \ldots, M.$$

Let $h_i(x)$ be the value of x_i for which the maximum stated in the preceding equation is attained. Each function $f_i(x)$ is an output function which sequentially adds the influence of the i-th input to the influence of the previous inputs. The value of $f_i(x)$ for any x is equivalent to the maximum value of the sum

$$\sum_{j=1}^{i} g_j(\alpha_j),$$

where the inputs are to satisfy the inequality

$$\sum_{j=1}^{i} s_j \, \alpha_j \leq x.$$

The procedure for arriving at an optimum solution involves the following operations:

(1) Calculate and tabulate the functions $f_1(x)$ through $f_M(x)$ and $h_2(x)$ through $h_M(x)$ for values of x ranging from 0 to C. This procedure represents, at each step, an optimization problem with one more input than was present at the previous step.

(2) Find the value of x between 0 and C such that $f_M(x)$ is a maximum. Denote this value of x as x(M). The quantity x(i) generated at any i-th step (in this and the next operation) represents the value taken on by the following sum when the values of α_i are chosen optimally:

$$\sum_{j=1}^{i} s_j \alpha_j$$

(3) Compute for each value of i from M down to 2, the function $h_i[x(i)]$. Denote this value as $\bar{x}_i$. Then $x(i-1) = x(i) - \bar{x}_i$. The optimum value of each α_i is then $\bar{x}_i/s_i$.

Sometimes the functions $g_i(\alpha_i)$ are defined for a continuous spectrum of values of α_i, rather than for a limited range. Then each function generated for values of x between 0 and C is defined analytically for a discrete set of R alternate values of x from 0 to C, such as 0, C/(R - 1), 2C/(R - 1), . . . , C, where R is some integer. In this case, the algorithm for the dynamic programming solution takes on the order of $MR^2/2$ comparisons and calculations of the functions g.

If the output E is a function (such as a product) of inputs, a transformation, such as logarithmic, may be applied to both inputs and output so that inputs and output will be in the form of equation (6).

The method of dynamic programming is feasible when the following conditions are present:

- The partial derivative $\partial E/\partial \alpha_i$ of the output with respect to any i-th input does not significantly depend on the value of the other inputs. This implies that the effects of the inputs upon the output are mutually independent.
- The service of an automatic computer is available.

Direct Comparison Method (Direct Search)

The simplest method to understand for optimizing the output of a system is to compute the output associated with each combination of input values for which none of the constraints are violated, and to determine the combination having the optimum output. This simple comparison method is very laborious due to the number of alternatives involved. For example, if there are M inputs and R_i alternative values for the i-th input, the number of alternatives to be investigated is $R_1 \times R_2 \times \ldots \times R_M$.

For 4 alternates to each of 10 input variables, the number of alternatives is over a million total combinations, unless a large number of alternatives can be eliminated through knowledge of the constraints involved. Even if a computer is available, the method of direct comparison is practical only when the numbers of inputs and alternative values for each input are sufficiently small to be manageable.

Gradient Projection Method

The gradient projection method is characterized by a change in the path of optimization whenever there exists a potential that a constraint may be violated. The procedure for using this method is as follows:

(1) Begin with an initial approximation for the inputs α such that no constraints are violated. Calculate the output E and the partial derivatives $\partial E/\partial \alpha_i$ corresponding to these inputs.

(2) Find those constraints, if any, for which there is little or no slack. This implies that C_k and f_k are approximately equal. Call these critical constraints, and let b represent the number of such constraints out of a total of c constraints. Thus, $b \leq c$. Arrange the c constraints so that the b critical constraints occur first. This is solely for the purpose of notational convenience. For each

of the critical constraints, calculate the derivative of the constrained function with respect to the input variables. Then add to each input α_i as follows:

$$\alpha_i + K\left(\frac{\partial E}{\partial \alpha_i} - \sum_{k=1}^{b} \frac{\partial f_k}{\partial \alpha_i} \psi_k \right),$$

where

$$\psi_k = \left[\sum_{i=1}^{N} \frac{\partial f_k}{\partial \alpha_i} \frac{\partial E}{\partial \alpha_i}\right] \Big/ \sum_{i=1}^{N} \left(\frac{\partial f_k}{\partial \alpha_i}\right)^2$$

The coefficient K is independent of i. It is chosen so that (1) the output function E computed for the new inputs α_i is greater than that computed for the inputs used on the previous iteration and (2) no constraint is violated by more than some fixed small amount. It is advisable to choose K as large as possible consistent with this rule. Iterative methods can be used to find the largest permissible value of K at each step.

(3) Change each input α_i to the following:

$$\alpha_i - \sum_{k=1}^{b} \frac{\epsilon_k}{D} \frac{\partial f_k}{\partial \alpha_i}$$

where

$$D = \sum_{i=1}^{N} \left(\frac{\partial f_k}{\partial \alpha_i}\right)^2$$

and ϵ_k is the amount by which the k-th constraint is violated. This amount is zero or $f_k - C_k$, whichever is greater.

(4) Repeat steps (2) and (3). Continue the process until the output E cannot be significantly improved.

The method of gradient projection normally will require the use of a computer.

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13. ABSTRACT

The manual defines and describes the system and cost effectiveness management implementation process which will provide both Air Force and contractor management with the necessary mission responsive criteria, authoritative perspective, and visibility for critical system development decisions. Technical activities, procedures, guidelines, and objectives for the efficient and meaningful formulation of effectiveness criteria, and for the evaluation and assurance of effectiveness, are detailed on a step-by-step and time-phased, action basis for each of the systems management phases of Concept Formulation, Contract Definition, and Acquisition. Further, the integration of the effectiveness implementation procedures with the system program management procedures (AFSCM 375-4) and systems engineering management procedures (AFSCM 375-5) is outlined for each major effectiveness activity and polarized with information flow networks. Also provided in the manual are guidelines for the necessary Air Force and contractor management actions to implement the effectiveness process and to insure attainment of its objectives. Finally, specific application guidelines are detailed for each of the six major classes of Air Force systems to provide intelligence on the needed technical translation of the general effectiveness procedures for specific applications.

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